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ABSTRACT

Speech intelligibility was tested in three classroom type spaces, one of 700 square feet, and two of 200 square feet, using student listeners and recorded test material. One of the latter two classrooms was fully carpeted. The test material used was Modified Rhyme Test (MRT) tapes, presented via tape reproducer and loudspeaker. Also investigated were the expected signal attenuation over distance in these classroom spaces and the effect of added noise on speech perception. Based on statistical analysis of the results of the tests, the following conclusions were drawn: the MRT tapes are a valuable research tool in determining speech intelligibility using live observers; there are no differences between the test lists; at the same level of presentation, there is no difference in speech intelligibility for female versus male speakers; and the signal attenuation in typical classroom spaces is a straight logarithmic function and approaches free field conditions in classrooms with large amounts of acoustical absorption on the floor and ceiling. From these results, a set of acoustic guidelines were drawn that can lead to significant improvement in speech perception in actual classrooms. (Author)

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FINAL REPORT

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November, 1969

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TABLE OF CONTENTS

Page

LIST OF CONTOUR MAPS. iv

LIST OF FIGURES vi

SUMMARY OF INVESTIGATION vii

CHAPTER I - INTRODUCTION 1
  Specific Objectives of This Study 1

CHAPTER II - METHODOLOGY. 3
  Speech Perception Test Material 6
  Signal Attenuation 11
  The Speech Level 11

CHAPTER III - EXPERIMENTAL TEST RESULTS AND ANALYSIS 18
  Speech Perception Test Scores as a Function of the SIL Signal to Noise Ratio 18
  Computer Contour Mapping (SYMAP). 19
  Required Input. 19
  The Test Results 22
  Basic Acoustic Conditions 23
  Speech Perception Test Results 24
  The Analysis of the Speech Perception Test Results 45

CHAPTER IV - DISCUSSION. 51
  The Application of the Experimental Test Results for the Developed Classroom Design Guidelines 51
  Figure 11. Rectangular Classroom Design Guidelines 53
  Range of Application of the Design Guidelines 55
  Comparison with Other Studies 56
  Suggestions for Future Research. 61

APPENDIX
A ROOM CHARACTERISTICS TEST RESULTS . . . 62
  A. 1. Reverberation Time, Averaged Test Results 62
  A. 2. Ambient Noise Data. 63
  A. 3. Ambient Noise + NC Shaped Noise Data 64
  A. 4. Broad Band Noise Distribution Data . . 66

TABLE OF CONTENTS (cont'd)

Page

APPENDIX
B SPEECH PERCEPTION TEST MATERIALS. . . 68
MODIFIED RHYME TEST. 69
MODIFIED RHYME FORM 1 70
MODIFIED RHYME FORM 2 71
MODIFIED RHYME FORM 3 72

C STATISTICAL ANALYSIS 73
C. 1. The Frequency Distribution of the Speech Perception Test Results . . . 73
C. 2. Correlation Between the Different Test Lists. 74
C. 3. Analysis of Variance Tests. 77

REFERENCES 81

LIST OF TABLES

TABLE I - SUMMARY OF ROOM CHARACTERISTICS . . . 5

TABLE II - SUMMARY OF ONE-WAY ANALYSIS OF VARIANCE TESTS 47

TABLE III - SUMMARY OF TWO-WAY ANALYSIS OF VARIANCE WITH REPEATED MEASURES ON ONE FACTOR. 49

TABLE IV - PREDICTED SPEECH INTELLIGIBILITY IN NOISE 60

TABLE V - SUMMARY OF CORRELATION TESTS 75

TABLE VI - ONE-WAY ANALYSIS OF VARIANCE NUMERICAL EXAMPLE 78

TABLE VII - TABLE FOR EXAMPLE OF ANALYSIS OF VARIANCE OF NESTED FACTOR DESIGN. 79

LIST OF CONTOUR MAPS

Map		Page
1	Ambient Noise Distribution Contours, 209 Keller, Values Given in SIL dB, AAC	25
2	Ambient Noise Distribution Contours, 312 Keller, Values Given in SIL dB, AAC	26
3	Ambient Noise Distribution Contours, 402 Keller, Values Given in SIL dB, AAC	27
4	Ambient Noise + NC-50 Distribution Contours, 209 Keller, 4/23, Values Given in SIL dB, AAC	28
5	Ambient Noise + NC-45 Distribution Contours, 312 Keller, 5/19, Values Given in SIL dB, AAC	29
6	Ambient Noise + NC-45 Distribution Contours, 402 Keller, 4/29, Values Given in SIL dB, AAC	30
7	Broad Band Noise Distribution Contours, 209 Keller, Values Given in SIL dB, 75 SIL dB 3 feet from Speaker, AAC	31
8	Broad Band Noise Distribution Contours, 312 Keller, Values Given in SIL dB, 79 SIL dB 3 feet from Speaker, AAC	32
9	Broad Band Noise Distribution Contours, 402 Keller, Values Given in SIL dB, 82 SIL dB 3 feet from Speaker, AAC	33
10	MRT Score Contours, 312 Keller, 10 Subjects, 5/19, Speech Level 66 dB Overall 3 feet from Speaker, Ambient Noise + NC-45, AAC	34
11	MRT Score Contours, 312 Keller, 10 Subjects, 5/19, Speech Level 66 dB Overall 3 feet from Speaker, Ambient Noise + NC-45, AAC	35
12	MRT Score Contours, 312 Keller, 6 Subjects, 5/22, Speech Level 62 dB Overall 3 feet from Speaker, Ambient Noise Only, GBC, SIL S/N = 52/34	36
13	MRT Score Contours, 312 Keller, 6 Subjects, 5/22, Speech Level 66 dB Overall 3 feet from Speaker, Ambient Noise Only, GBC, SIL S/N = 56/34	37

LIST OF CONTOUR MAPS (cont'd)

Map		Page
14	MRT Score Contours, 209 Keller, 14 Subjects, 4/23, Speech Level 69 dB Overall 3 feet from Speaker, Ambient Noise + NC-50, AAC	38
15	MRT Score Contours, 402 Keller, 13 Subjects, 4/29, Speech Level 66 dB Overall 3 feet from Speaker, Ambient Noise + NC-45, AAC	39
16	MRT Score Contours, 312 Keller, 11 Subjects, 4/30, Speech Level 66 dB Overall 3 feet from Speaker, Ambient Noise + NC-40, AAC	40
17	MRT Score Contours, 312 Keller, 9 Subjects, 5/28, Speech Level 62 dB Overall 3 feet from Speaker, Ambient Noise Only, AAC, SIL S/N = 52/34	41
18	MRT Score Contours, 312 Keller, 6 Subjects, 5/22, Speech Level 62 dB Overall 3 feet from Speaker, Ambient Noise Only, GBC, SIL S/N = 52/34	42
19	MRT Score Contours, 402 Keller, 9 Subjects, 5/26, Speech Level 62 dB Overall 3 feet from Speaker, Ambient Noise Only, AAC, SIL S/N = 52/32	43
20	MRT Score Contours, 402 Keller, 9 Subjects, 5/28, Speech Level 62 dB 3 feet from Speaker, Ambient Noise Only, GBC, SIL S/N - 52/32	44

LIST OF FIGURES

Figure No.		Page
1	Classroom Volume, Floor Area and Module Length	4
2	Classroom Length and Width	4
3	Reverberation Times in the Tested Rooms	7
4	Ambient Noise Levels in Center of Tested Rooms, Given in SIL dB	8
5	Subject Locations in the Tested Rooms	12
6	Broad Band Noise Attenuation in the Tested Rooms	13
7	Spectrum of Idealized Speech (20).	15
8	Octave Band Analysis of Speech Material Recorded Three Feet from Speaker	16
9	Octave Band Analysis of Speech Material Recorded Fifty-four Feet from Speaker	17
10	Speech Perception Test Results as a Function of SIL Signal to Noise Ratio	52
11	Rectangular Classroom Design Guidelines	54
12	Relationship Between Articulation Index and Speech Intelligibility (20)	58

SUMMARY OF INVESTIGATION

Speech intelligibility was tested in three classroom type spaces, one of 700 sq ft, and two of 2000 sq ft, using student listeners and recorded test material. One of the latter two classrooms was fully carpeted. The test material used was Modified Rhyme Test tapes, presented via tape reproducer and loudspeaker. Also investigated were the expected signal attenuation over distance in these classroom spaces and the effect of added noise on speech perception.

Based on statistical analysis of the results of the tests, the following conclusions were drawn:

1) The MRT tapes are a valuable research tool in determining speech intelligibility using live observers.

2) There are no differences between the test lists.

3) At the same level of presentation, there is no difference in speech intelligibility for female vs male speakers.

4) The signal attenuation in typical classroom spaces is a straight logarithmic function and approaches free field conditions in classrooms with large amounts of acoustical absorption on the floor and ceiling.

From these results, a set of acoustic guidelines are drawn, based on noise level in the room and distances between speaker and listener, that can lead to significant improvement in speech perception in actual classrooms.

Additional research is suggested in the areas of actual levels of speech presentation by male and female teachers, under real classroom conditions; extension of the research into classroom shapes other than rectangular, and from these into "open plan" classrooms.

CHAPTER I

INTRODUCTION

It seems beyond question that adequate understanding of speech should be an important criterion for any classroom of any design at any level of education, since so much information transfer occurs by the spoken word. Given this circumstance it seems remarkable, indeed, that there is so little published information on speech perception in classrooms with varying conditions of size, background noise and other acoustical design considerations. In a previous report (Kingsbury and Taylor, 1967), the extant literature was surveyed and guidelines established for the design of enclosed school classrooms. These guidelines were based on two primary acoustical parameters - reverberation time requirements and calculated values of the Articulation Index (AI). The latter is, essentially, a calculation that indicates probable speech intelligibility based on the signal-to-noise ratio predicted at the ear of the listener. In the classroom context, the signal is from the teacher speaking, attenuated or (possibly) distorted over the path from teacher to student and the noise is the ambient and background noise generated by heating and ventilating equipment within the room, activities in adjacent spaces, exterior noise penetration, etc. Required data or estimates for input for these calculations indicated two areas for which no direct information was available, 1) the nature and amount of signal attenuation that occurs over distance in typical classrooms, and 2) the AI calculation has not been validated for the female speech spectrum. Accordingly, this investigation is concerned primarily with these two questions, and their implications in classroom design. While the results of this investigation are limited to the specific circumstances involved, and do not reflect work in other room designs, it is believed that the data contained are broadly applicable to the design of self-contained classrooms at the secondary or collegiate level.

Specific Objectives of this Study

As mentioned, this study is concerned with the design of rectangular, closed classrooms. Some acoustic characteristics of rectangular classrooms can be determined by computation methods, for example optimal reverberation time at 500 Hz. This optimum reverberation time value depends solely on the volume of the designed space and is given as a design recommendation (Fitzroy and Reid, 1963). Once the optimum reverberation time is known, the volume and dimensions of the rectangular classroom for n students occupancy can be determined assuming constant ratios between room dimensions and area/student. Then from this, the required additional acoustical absorption can be determined. However, for speech perception in those enclosures, the signal to noise ratio, and speech intelligibility as a function of the signal to noise ratio must be known.

The specific objectives of this study, as outlined in the original proposal are to determine by experimental means speech signal attenuation and perception in enclosed spaces similar to classrooms and to determine the effect of female vs male speech spectrums on the perception. These are then incorporated into a series of acoustical design guidelines for rectangular classrooms of from about 750 to 2000 sq ft, where the acoustic quality is rated by means of speech intelligibility.

CHAPTER II

METHODOLOGY

The rooms selected as test spaces are located in the J. Orvis Keller Building, on the Pennsylvania State University campus. This building is primarily a conference center, and many of the rooms are quite similar in design to classrooms. Three were selected for the test spaces. Room 209 met the criteria for a classroom of about 900 sq ft. Rooms 312 and 402 met the criteria for the classrooms of about 1800 sq ft. Fortuitously, these latter two rooms are essentially identical, except that 402 has a fully carpeted floor. As can be seen from the room description, these rooms are quite similar to conventional secondary school classrooms, with the exception of the furniture. See Table I for room characteristics.

Room 209

Size - 33' x 21' x 9'6", Volume 6600 cu ft.
Surface Finishes - Walls, painted concrete block; Floor - vinyl asbestos tile; Ceiling - suspended 5/8" thick fibrous panels, 24" x 48".
Heating and Ventilating Equipment - Fan-coil units on two walls, ducted exhaust.
Furnishings - Plastic covered, upholstered chairs, tables.

Room 312

Size - 63' x 32' x 9'6", Volume 19,100 cu ft.
Surface Finishes - as in Room 209.

Room 402

Size - 63' x 32' x 9'6", Volume 19,100 cu ft.
Surface Finishes - as in 209, except - floor - carpet over pad - Lee's "Bold Venture" over sponge rubber.

The existing acoustical conditions were analyzed by determining the reverberation times, at one or more locations, and measuring the ambient noise level at several positions in each room.

The reverberation time was determined by playing back pre-recorded tape loops of 1/3 octave band width white noise through a tape recorder, high quality amplifier and loudspeaker. In all cases, the loudspeaker was located at the center of the front of the room, corresponding roughly to an expected teacher location. The signal from this equipment was analyzed by passing through a sound level meter, 1/3 octave band analyzer and graphic level recorder.

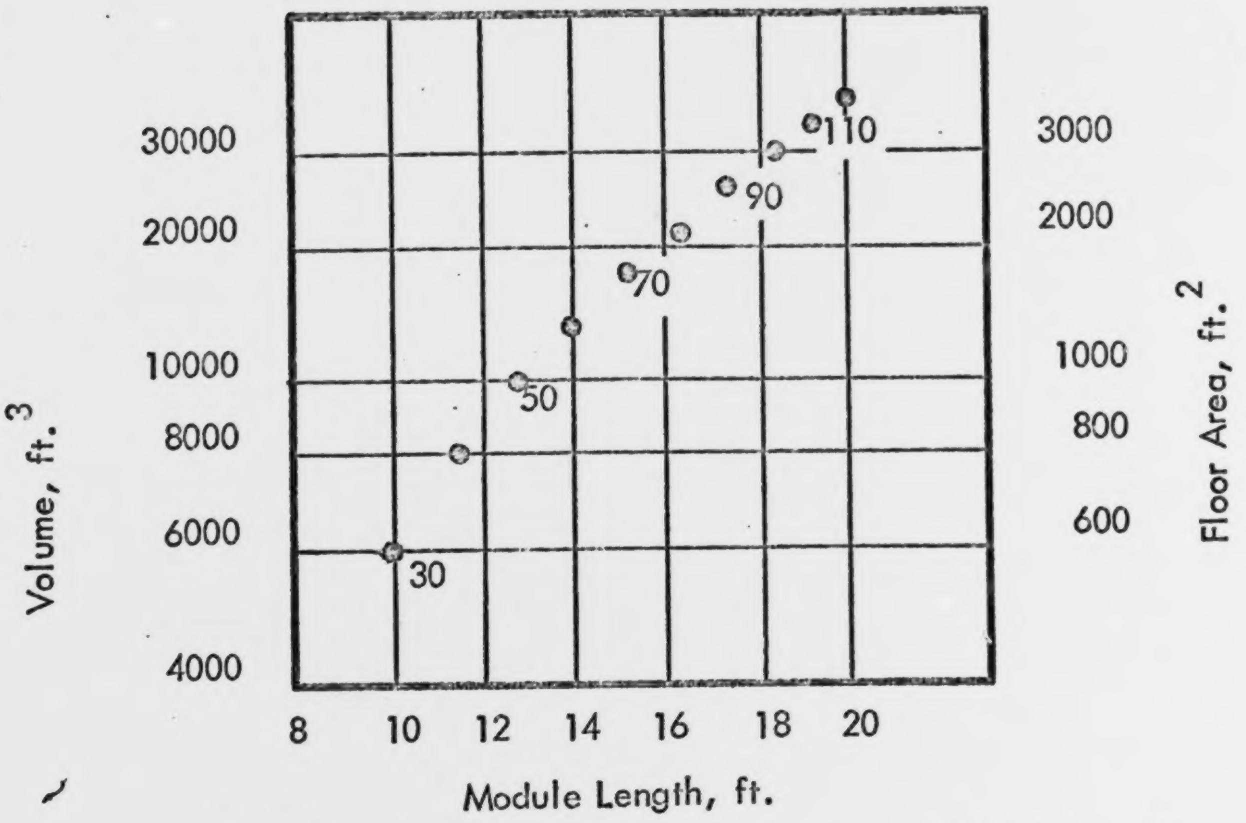


Figure 1. Classroom Volume, Floor area and Module Length

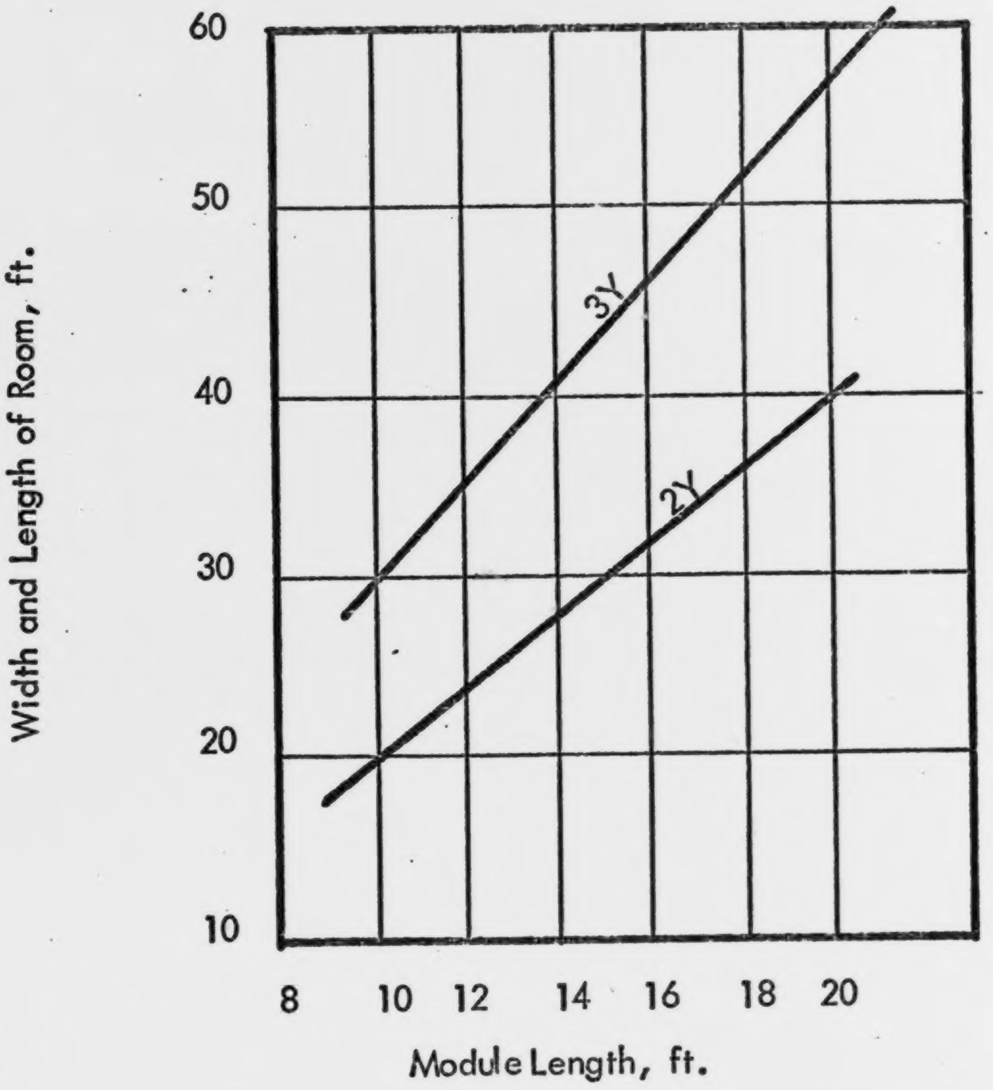


Figure 2. Classroom Length and Width

TABLE I

SUMMARY OF ROOM CHARACTERISTICS

Room	Floor Area ft^2	Volume ft^3	$\bar{\alpha}^1_{500}$	R^1_{500} ft^2	$\bar{\alpha}^2_{500}$	R^2_{500} ft^2	Remarks
209 L B H 33' 21' 9'6"	693	6,584	0.352	1310			Chairs: 25 Tables: 8 Estimated Occupants: 25
312 L B H 63' 33' 9'6"	2079	19,750	0.311	2700	0.257	1377	Chairs: 100 Tables: 32 Estimated Occupants: 100
402 L B H 63' 33' 9'6"	2079	19,750	0.433	4568	0.344	3137	Chairs: 100 Tables: 32 Estimated Occupants: 100 Carpeted floor

$\bar{\alpha}^1_{500}$ Avg. Absorption Coef. at 500 Hz, for AAC.

R^1_{500} Room Constant at 500 Hz, for AAC.

$\bar{\alpha}^2_{500}$ Avg. Absorption Coef. at 500 Hz, for GBC.

R^2_{500} Room Constant at 500 Hz, for GBC.

AAC - Acoustical Absorbing Ceiling

GBC - 50% Gypsum Board Ceiling

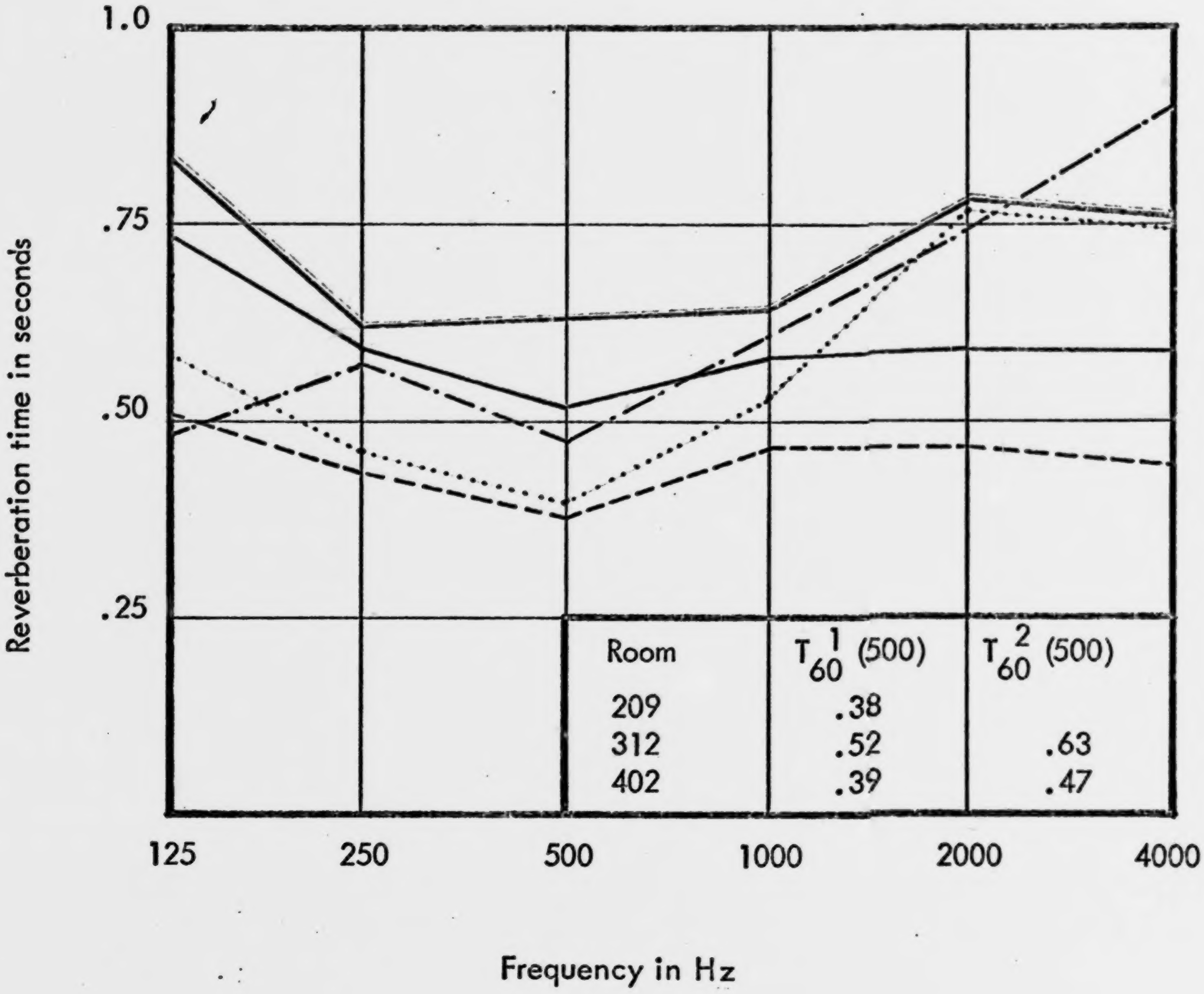
Ten decays were recorded at each frequency. The frequencies used were the 1/3 octave bands centered at 125, 250, 500, 1000 and 2000 Hz. (See equipment list in Appendix A) The data obtained from these measurements are shown in Fig. 3 and in Appendix A. The same series of measurements was repeated after changing the suspended ceiling absorption characteristics by replacing 50% of the acoustical absorption material with 1/2" gypsum board.

Ambient noise levels were measured in each room, unoccupied. The primary sources of this ambient noise were the fan-coil units used for heating, ventilating and air-conditioning and the fan noise from the exhaust ducts. The noise level was measured at each observed position, at desk height. Measurements were taken for overall level, and for the octave bands centered at 125, 250, 500, 1000, 2000 and 4000 Hz. Figure 4 shows the level as a function of frequency for the approximate center of the classroom. All the data, in SIL dB, are given in Appendix A.

A key element in determining what the signal-to-noise ratio is at the observer position, which in turn largely determines intelligibility, is the attenuation of the signal over the path from the speaker to the listener. Certain predictions of this signal attenuation, based on diffuse room theory (Beranek, 1954) are of questionable validity in rooms similar to classrooms, where most of the absorption is concentrated on two surfaces - the ceiling, and the floor (the occupants). Consequently, an important item of determination was the attenuation of the signal from the front to the back of the classroom. In this determination, broad band "white" noise on a prerecorded tape loop was played back through the same tape recorder-amplifier-speaker system used for all tests. First, overall levels and an analysis by octave bands was made at each observer position. Then, as a second determination, similar overall and octave band measurements were made along the centerline of the room length for successive doublings of distance, starting at three feet from the speaker. Data from these tests are also in the next section.

Speech Perception Test Material

There were a number of choices available in determining the method of conducting the intelligibility tests. The first choice was the test material to be used. Speech perception, or more precisely speech intelligibility, and speech articulation tests have been used for many years for the evaluation of communication systems at high ambient noise levels. They were first developed during World War II at the Psychoacoustic Laboratory at Harvard University. Those interested in speech audiometry then developed a similar test for a different purpose - namely to find the hearing ability of the tested subject. The speech material consisted of spondaic word lists, the CID Auditory Tests W-1 and W-2, in addition to the monosyllabic



Room	T_{60}^{1} (500)	T_{60}^{2} (500)
209	.38	
312	.52	.63
402	.39	.47

T_{60}^{1} (500) - Acoustical Ceiling – – – – 209
T_{60}^{2} (500) - 50% Gypsum Board ═════ 312
T_{60}^{1} (500) - Acoustical Ceiling ────── 312
T_{60}^{2} (500) - 50% Gypsum Board -.—.—.. 402
T_{60}^{1} (500) - Acoustical Ceiling 402

Figure 3. Reverberation Times In The Tested Rooms

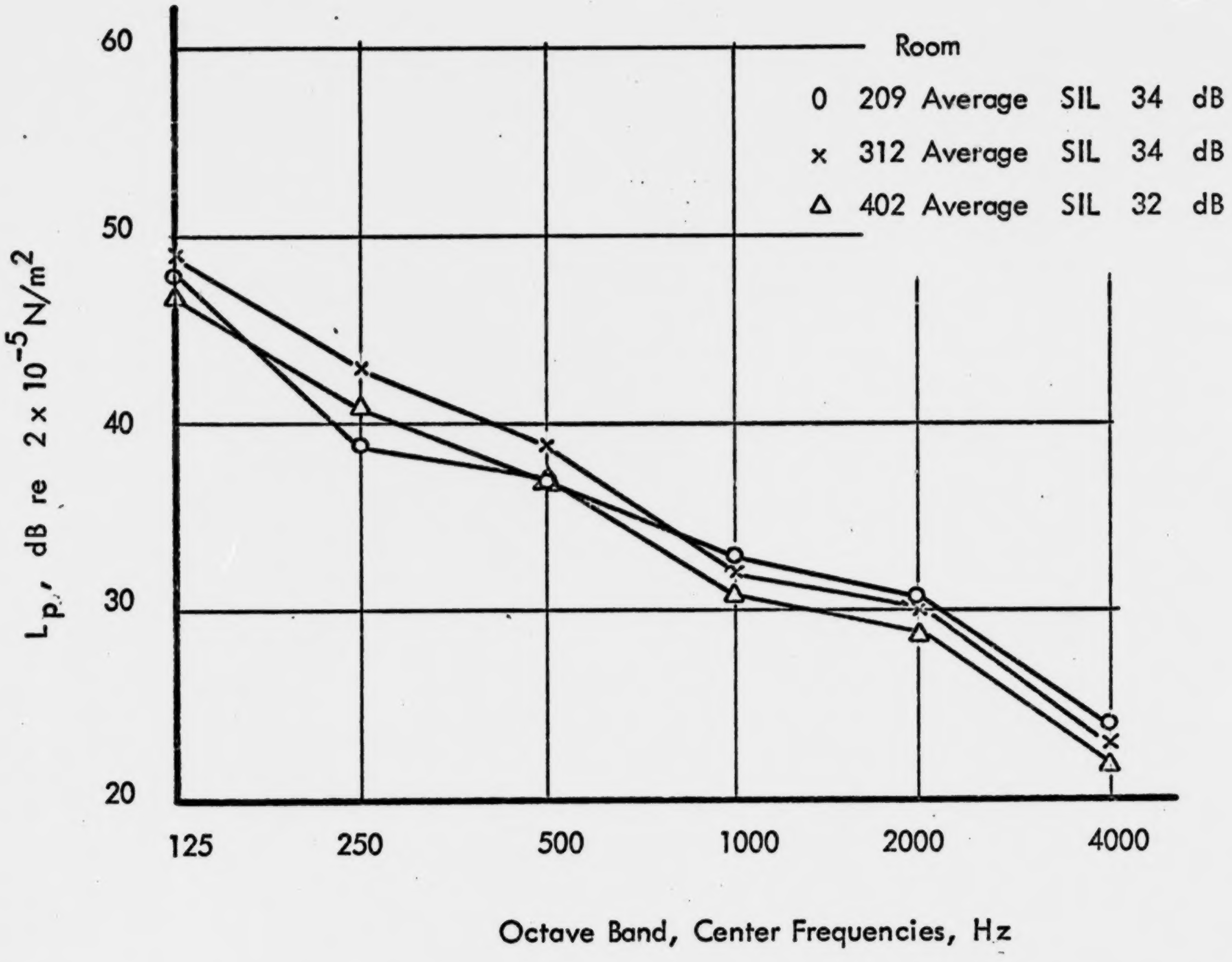


Figure 4. Ambient Noise Levels in Center of Tested Rooms, Given in SIL dB

CID Auditory Test W-22. Four main categories of useful speech perception test material are also indicated by Beranek (1949). They are nonsense syllables, monosyllabic words, spondaic words and sentences. Egan (1948) reported on the application of the different articulation testing methods, which were described as tedious and very time consuming.

The Fairbanks Rhyme Test (FRT) was introduced by Fairbanks (1958), for the primary purpose of assessing speech perception. Prior to its introduction, the assessment of speech perception was obtained mainly by using CID Auditory Test W-22 (Hirsh et al, 1952). The main difference between the two tests is that the FRT forces the subject to choose his answer from a given set of responses, whereas in the latter the subject's choice of responses is infinite. Other possible favorable characteristics of the FRT are: (1) involves less subjective evaluation on the part of the examiner when compared to other tests, (2) appears to depend less on the subject's vocabulary and articulatory proficiency, and (3) allows for the responses to be analyzed in terms of phonemic construction.

Since the introduction of the FRT, it has been subjected to a number of studies to substantiate its validity and reliability. A study by Nickerson, et al (1961) compared the FRT with other similar tests in terms of administering efficiency and signal-to-noise ratios. Results showed that the FRT yielded higher scores than the W-22 in various signal-to-noise situations, but that the mean of the scores for the FRT was close to the mean of the scores for all tests used, and that the FRT required considerably less administration time than the other tests. They concluded that the FRT was the most useful and efficient of the tests investigated.

High, et al (1964) presented stimuli from both the W-22 and FRT to a sample of hearing impaired subjects. Stimuli was presented at 40 dB SL and the difference between mean scores for the two tests was found to be less than 1%.

Schultz and Boros (1965) compared scores obtained on the FRT, W-22 and two other similar tests. They used hearing impaired subjects whose etiology resulted from Meniere's Disease, acoustic trauma and presbycusis. Stimuli was presented at 30 dB SL. Results showed that all the groups, regardless of their etiology, scored better on the FRT.

Kopra and Blosser (1968) administered the FRT and the W-22 tests to fifteen listeners with sensorineural pathology and fifteen normal listeners at sensation levels of -4, 0, 8, 16, 24, 32, 40 dB. The most important finding of this study was the great similarity between the articulation curve functions for the two tests and for the two groups of listeners, thereby advocating that both tests appeared to be equivalent indicators of speech-sound discrimination.

The Modified Rhyme Test (MRT) is similar in general respects to the FRT (House, et al, 1965). It differs, however, in the constraints imposed on the word lists, the words themselves and on the listener task. The major innovation in the test is the listener task. For each test word, the listener has available a closed set of six words from which to choose that which he heard. Since the response sets are generated from these sets, the listener has available to him the complete message set. This procedure has the built-in advantage that it eliminates the learning process inherent in previous tests and allows the usage of untrained observers. Repeated exposure to the same test material should not result in improved scores. The usage of known message sets also should eliminate variations in response due to word-frequency effects (Pollock, et al, 1959). The lack of learning effect has been validated both by House and Kreul.

The original intent was to record this test material on tape, using local speakers. However, it was learned after the inception of the research that a series of tapes of this test material, prepared under carefully evaluated conditions, would be available, including both female and male speakers (Kreul, et al, 1968). While these tapes were prepared for another purpose and as standardly available have shaped spectrum noise in addition to the test material, they were obtained free from such noise, by arrangement. Since these tapes have been prepared and analyzed with considerable care, they are particularly valuable.

The use of tape recorded material vs live speaker has several advantages. The most obvious is the availability and repeatability of the test material under closely reproducible conditions. While electronic reproduction systems are subject to a number of faults, reasonably careful choice of components should result in appropriately realistic speech. The characteristics of the system used, including directively and frequency response of the speaker were checked carefully.

Actual teacher speaking position in a classroom varies considerably, depending on a number of factors. For the purposes at hand, a fixed position was desirable, consequently, the speaker was placed 5' above the floor at the front center of the room, 3' from the wall.

The listeners were recruited from the undergraduate student population. Since all students at Penn State must undergo an audiometric survey, it was no problem to determine if those recruited had normal hearing. All spoke American English as their first language. In our recruitment, emphasis was placed on continuity of attendance during the testing program, which was always held during the evening for minimum conflicts. Continuity of attendance, or rather the lack of it, was one of the problems encountered. Approximately twenty observers were desired for each session. Over forty listeners agreed to participate, yet only six to ten came regularly, in spite of the fact each was paid for each test session.

Figure 5 shows the listener's locations in each of the test rooms. The coordinates of these locations are the same as for the data given in Appendices A. 2., A. 3. and A. 4.

Preliminary speech perception tests (data not given here) showed that, with the normal ambient noise conditions alone, the range of obtained test scores for a specific test condition was rather narrow. It was decided, therefore, to employ an additional noise source in the room. The noise source was placed in the rear part of the room and produced NC shaped noise. The noise levels were changed under different test conditions. The SIL levels are given for the data in Appendix A. 3. The discussion of the obtained levels and their influence on the speech perception will be given in the later chapters.

Signal Attenuation

The following procedure was used to determine the signal attenuation at different locations in the room (data which are required in order to judge the speech intelligibility at the listener's location). A broad band noise on a prerecorded tape was played back through the same amplification system used for the speech perception tests. First, overall levels and an analysis in octave bands were made at each listener's location. Then as a second determination, similar overall and octave band measurements were made along the centerline of the room length for successive doublings of distance, starting three feet from the speaker. All the data were also analyzed as SIL and used as an input for the computerized regional mapping SYMAP (Degelman, 1969) which will be discussed in the next chapter. The above data in SIL dB are given in Appendix A. 4.

Figure 6 shows the signal attenuation along the center length line in the three tested rooms. The influence of the room constant is clearly seen. The attenuation can be approximated as an inverse function of the distance depending on the room constant.

For all practical purposes, the test procedures are concerned only with the speech perception testing. This procedure is a three step measurement, first, the measurement of the play-back level of the speech material, or in other words, the speech level, second, the measurement of the background or ambient noise, and third, the actual speech perception tests.

The Speech Level

The actual teacher speaking position in any real room varies considerably, depending on a number of factors; however, for the purposes at hand, a fixed position was desirable. Consequently, the speaker was placed five feet above the floor at the front center of the room, at three feet from the front wall in Room 209 and six feet from the front wall in Rooms 312 and 402.

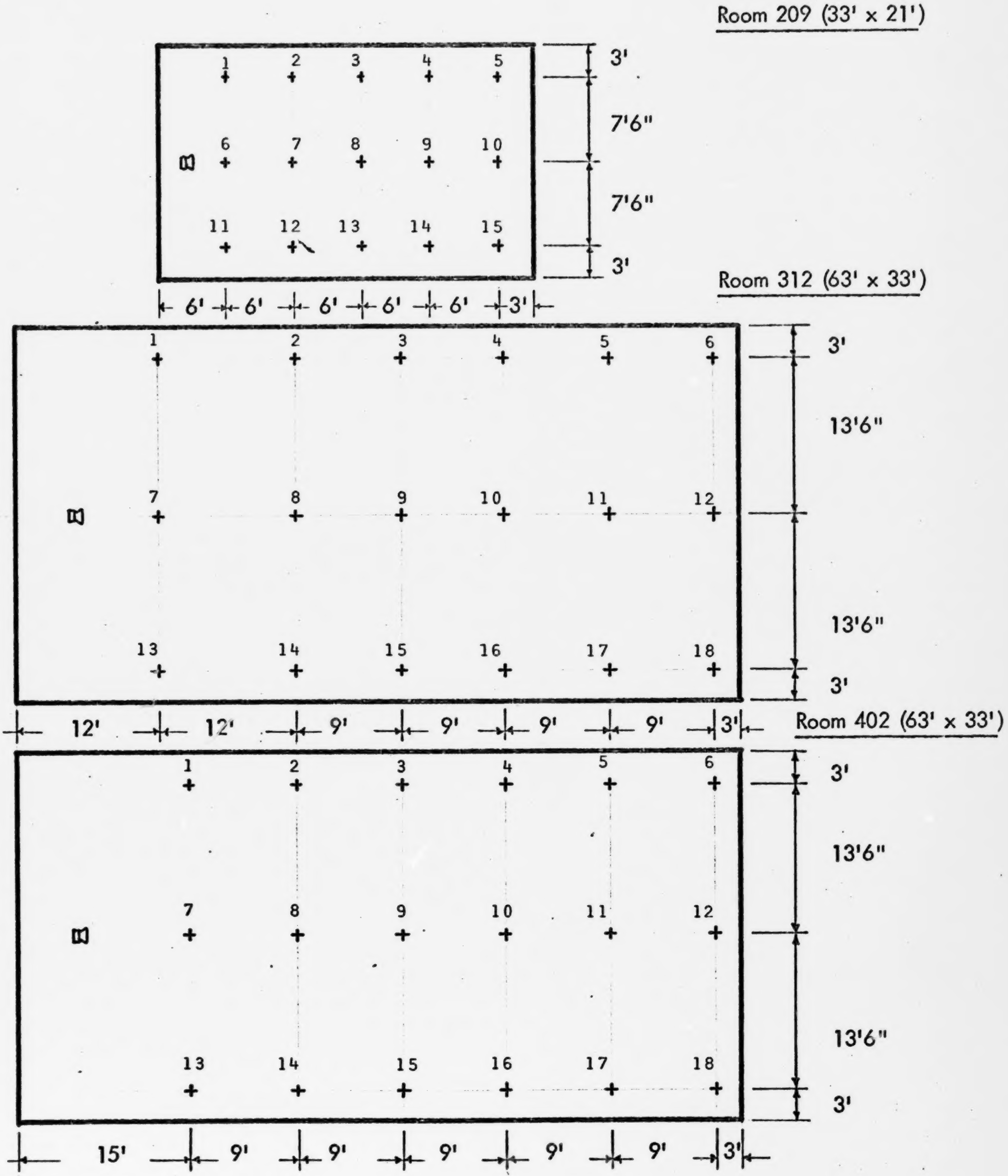

Room 209 (33' x 21')
1 2 3 4 5
6 7 8 9 10
11 12 13 14 15
3'
7'6"
7'6"
3'
6' 6' 6' 6' 6' 3'
Room 312 (63' x 33')
1 2 3 4 5 6
7 8 9 10 11 12
13 14 15 16 17 18
3'
13'6"
13'6"
3'
12' 12' 9' 9' 9' 9' 3'
Room 402 (63' x 33')
1 2 3 4 5 6
7 8 9 10 11 12
13 14 15 16 17 18
3'
13'6"
13'6"
3'
15' 9' 9' 9' 9' 9' 3'

Figure 5. Subject Locations In The Tested Rooms

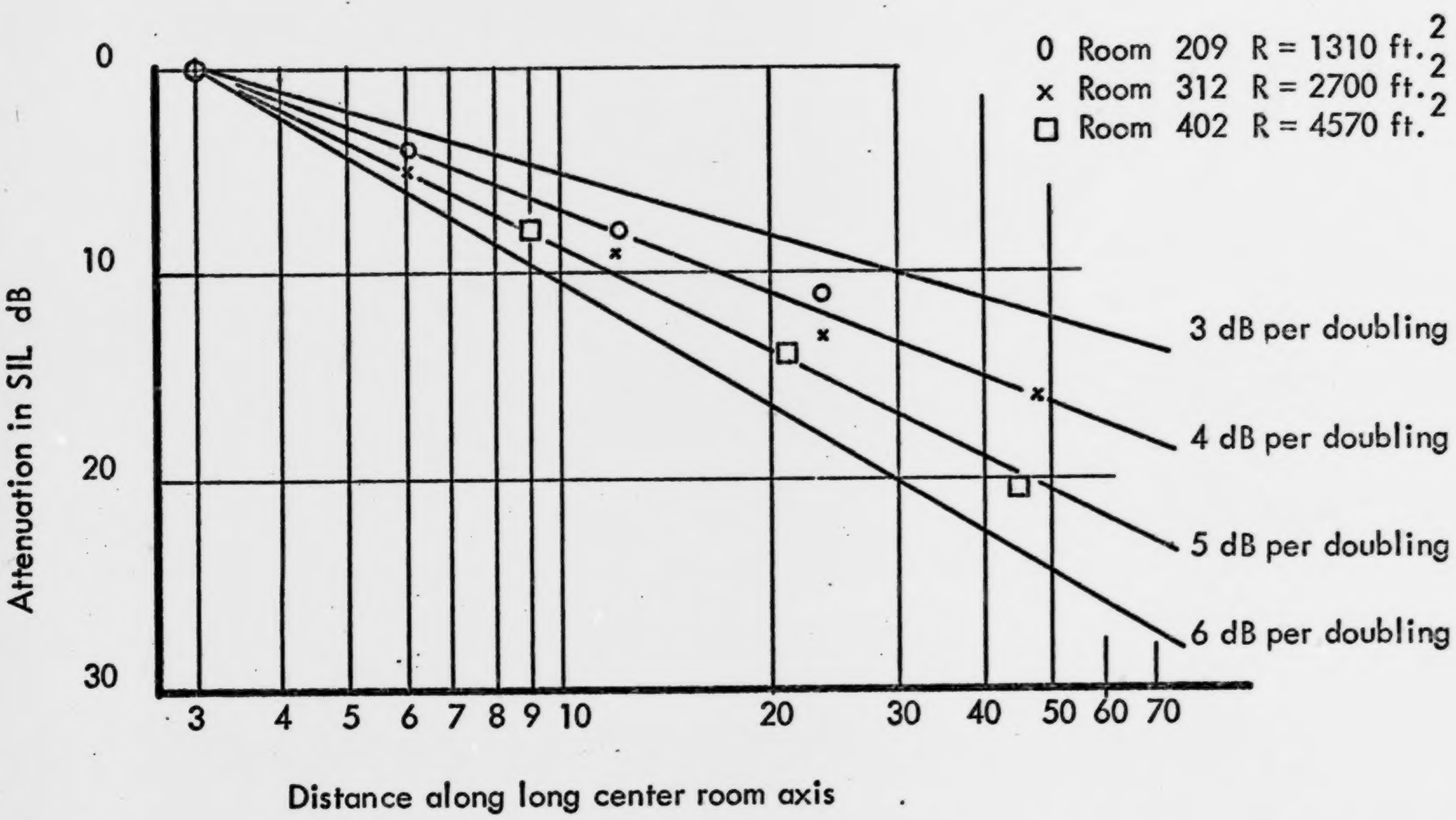


Figure 6. Broad Band Noise Attenuation In The Tested Rooms

The quasi-rms overall averaged speech level was measured at three feet from the speaker along its center axis, using a sound level meter on "C" scale. This measurement was then related to the rms overall idealized speech level (see Figure 7), as given by Kryter (1962). In other words, the measured rms overall speech level was identified with the rms overall idealized speech level. Thus it became possible to use the spectrum of the idealized speech level in our calculations. Once the spectrum was known, the SIL could be computed. Kryter's assumption that increasing or decreasing the speech level means a parallel shift in the frequency spectrum was adopted. The SIL values for any measured rms overall speech level could then be computed.

Figures 8 and 9 show data obtained from an octave band analysis of different words of played back MRT speech material. The measuring setup included a sound level meter, octave band analyzer, and a level recorder. The measurements were carried out in Room 312 at three feet from the speaker (Figure 8) and at fifty-four feet from the speaker (Figure 9). The spectrum shape of the different words, the sound pressure level range among words and the close to parallel shift of the spectrum (distance influence) can be readily observed on these two figures.

After instructing the listeners both orally and with the aid of a trial tape (see instruction sheets in Appendix B), the tests were undertaken. The test material was played back via an amplification system, and the listeners marked the heard words. In most cases three, five, or six tests were conducted, giving a break of five minutes between successive tests.

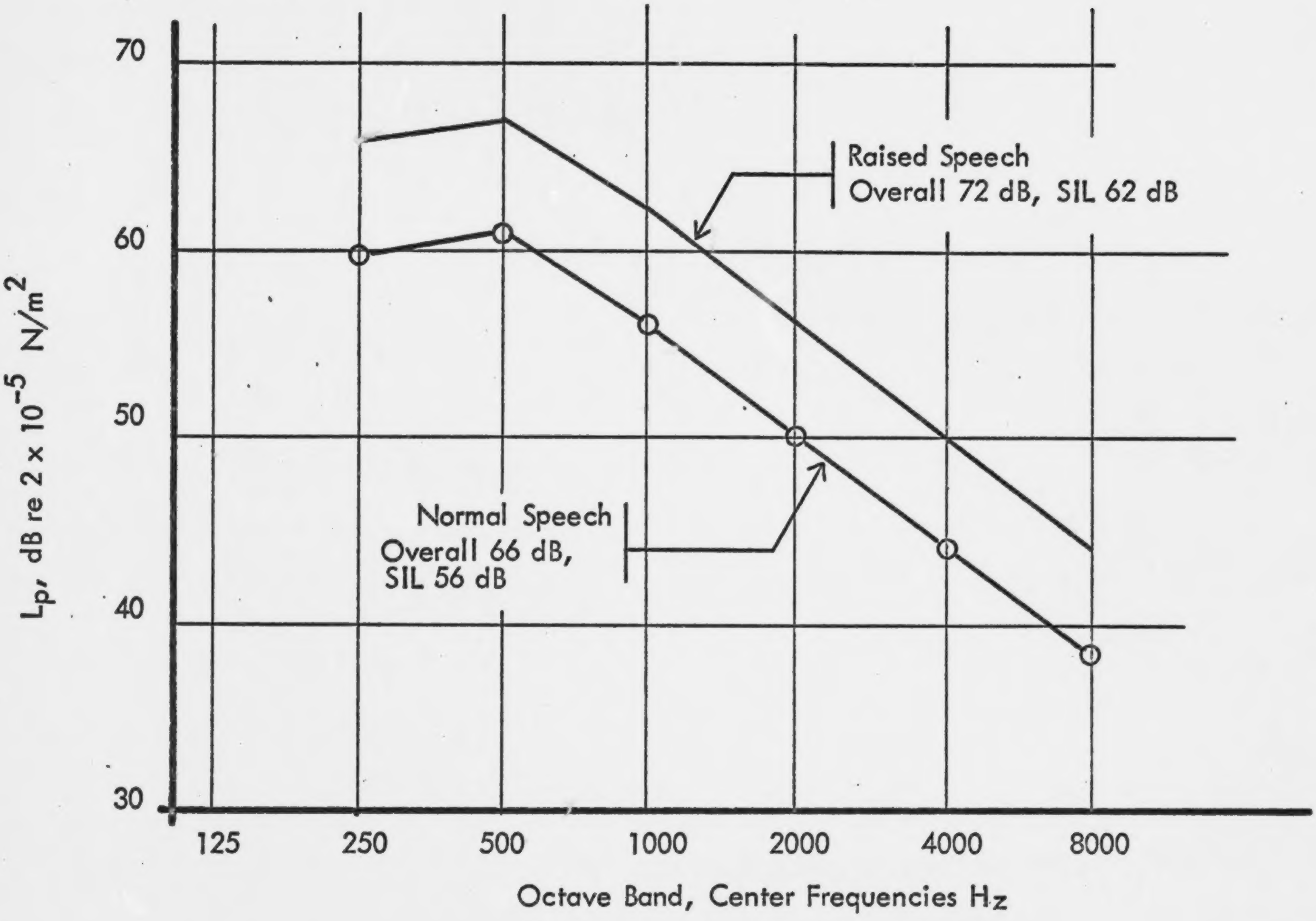


Figure 7. Spectrum Of Idealized Speech (20)

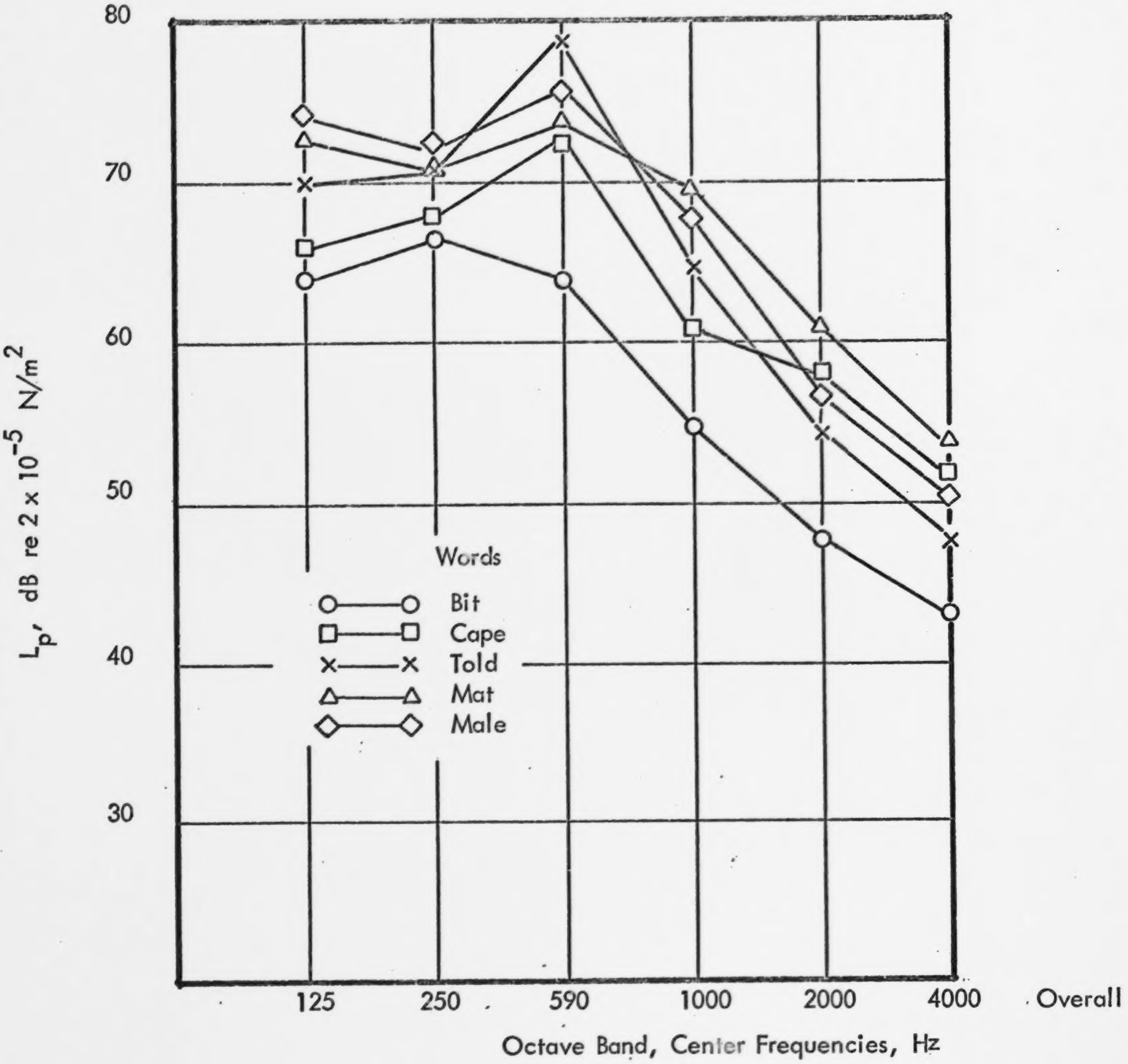


Figure 8. Octave Band Analysis Of Speech Material Recorded Three Feet From Speaker

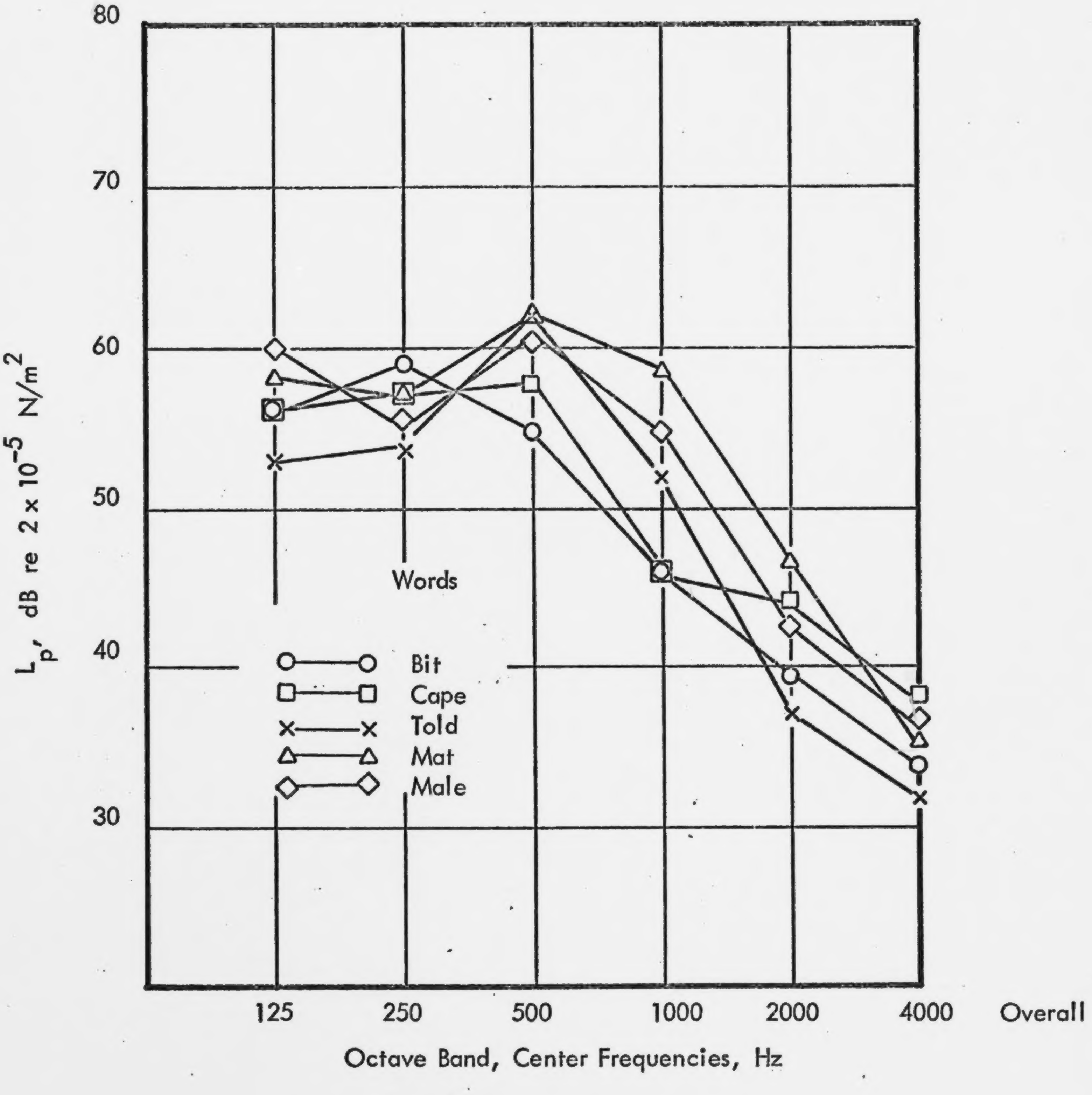


Figure 9. Octave Band Analysis Of Speech Material Recorded 54 Feet From Speaker

CHAPTER III

EXPERIMENTAL TEST RESULTS AND ANALYSIS

One of the problems related to the data analysis was the use of a measure that would describe the noise conditions at the point of measurement (the listener's position) more accurately. This was overcome by applying the speech interference level signal to noise ratio, which is discussed in detail in the next section.

One method of presenting speech perception test results of a particular test session could be listing the data or giving it as a table. Another method of data presentation is to apply computer regional plotting. By applying this method contours are drawn between all points that have the same numeric value. This presentation permits visualization of the often complex data distribution. The presented data are arranged in a number of levels showing the range of numeric values. In this study computer regional plotting was applied for the description of the ambient or background noise, signal attenuation and speech perception in the classrooms tested.

The speech perception test results given in this chapter relate to the specific problems that were investigated in this study. The MRT was used in this study. Its "calibration", however, was checked by testing the differences among test lists. Other influences are reflected in the speech perception test results. These include subject variability, different levels of speech material presentation, background or ambient noise and the influence of different rooms. The obtained data were statistically analyzed and are presented as raw data as well as computer regional plots.

Speech Perception Test Scores as a Function of the SIL Signal to Noise Ratio

Speech Interference Level (SIL) is defined as the arithmetic average value of the measured sound pressure level of the three octave bands centered at 500, 1000 and 2000 Hz. This quantity provides a guide to the interfering effect of noise on speech, as it measures the noise in the most important part of the speech frequency range.

In this study speech perception is studied under various environments and noise conditions. It was felt that in order to be able to define the speech perception test score as a function of the noise, a more specific measure of the noise was necessary. It was, therefore, decided to use the SIL signal to noise ratio as such a measure. The last can be defined as the arithmetic difference between the SIL values of the speech and the noise, given in dB.

In this study the SIL signal was obtained in the following way. For a given speech level, the overall level value was measured at a distance of three feet from the speaker. The speech spectrum was then obtained by referring to the idealized speech spectrum. Once the spectrum was known, the SIL value was computed according to its definition. For the ambient or for background noise, SIL was computed according to its definition from the measured octave band spectrum.

Computer Contour Mapping (SYMAP)

A computerized contour mapping program is used for data display - SYMAP. The mathematical model and programming were developed originally at the Laboratory for Computer Graphics at Harvard University (Shepherd, 1960). The version used at The Pennsylvania State University was applied in this study.

In principal, SYMAP can produce different kinds of regional plots. Here, however, only the contour mapping was used. The contour map is best described as follows:

> The contour (or isoline) map consists of close curves known as contour lines, which connect all points having the same numeric value. Contour lines emerge from a datum plane at selected levels which are determined from the scale of the map and the range of the data. Between any two contour lines, a continuous variation is assumed. Therefore, the use of contour lines should be restricted to the representation of continuous information, such as topography, rainfall and population density.

In this study contour mapping is applied for different kinds of input data - sound pressure levels and speech perception test scores. Part of the mapping procedure will be the same in both cases. It is preferred, however, to give some general instructions for the computer mapping procedure, which will enable the application of any kind of input data.

The rather general instructions given in this section are taken from the SYMAP manual, which should be consulted for the preparation of computer contour maps.

Required Input

To produce computer maps, input to the computer in the form of a deck of punched cards must be prepared. This deck will consist of certain introductory cards and a number of "packages", each composed of additional cards covering a specific category of information about the map to be produced.

1. Introductory Cards*

Certain introductory cards (as required by the computing center being used) will need to be provided first - together with a copy of the SYMAP program on cards, on tape or on the Computer Center's Library. Instructions for the cards necessary for submissions at the Penn State Computation Center will be found in a later section of this manual. (Appendix B)

2. Types of Packages*

The titles of all available packages, with a brief explanation of their general purpose, are listed below in the sequence of their position in the deck. For more complete and definitive instructions in the preparation of these packages, see the section entitled PREPARATION OF PACKAGES.

A-OUTLINE*

This package describes the outline of the study area if non-rectangular, by specifying the coordinate locations of the outline vertices. (Used for contour and proximal maps only.)

A-CONFORMOLINES

This package is used to give the positions of the data zones to which your data is to be related, by specifying the coordinate locations of vertices on the zonal outlines. This package is required for a conformant map.

B-DATA POINTS*

This package is used to give the positions of the data points to which your data is to be related, by specifying their coordinate locations. Data points may be either the points for which data are available, or the centers of areas, called data zones, for which data are available. (When warranted by the nature of your study, and under exceptional circumstances, other "centers" may be used, such as centers of population.) This package is required for contour and proximal maps.

C-LEGENDS

This package is used to cause certain supplementary information, called "legends", to appear on the face of your map (information regarding the scale, the compass directions, etc.) by specifying their coordinate locations and content. This package has been obsoleted by the following package, but is available for the possible convenience of users of previous versions of SYMAP.

C-OTOLEGENDS*

This package is used to specify the relative position of legends which are to be adjusted automatically if the size and/or scale of the map are altered.

D-BARRIERS

This package is used to give the coordinate location and strength of impediments to interpolation at specified vertices.

E-VALUES*

This package is used to assign numerical data to the data points and/or data zones, by specifying the "values" involved. All such data must, of course, be measured on a consistent uniform basis. (While normally required, this package may be omitted if you wish to procure a preliminary "base map" for checking locations before applying values.)

E1-VALUES INDEX

This package is used to adjust the reference order of data values in the E-VALUES package.

F-MAP*

This package is used to specify below the map an appropriate title for the identification of each separate map you may wish to run. In addition, it instructs the computer to make each specific map pursuant to certain "electives." These electives provide a variety of options for obtaining maps suited to your particular needs. An F-MAP package is required for each map desired.

In this study only the instructions marked with an asterisk (*) were applied, and so were the electives 1, 2, 3, 4 and 5 which provide the computer with additional information required for the programming.

The first elective discusses the size of the contour map. This refers to the area of the study, which in the classroom case was the seating area. The second elective discusses the extreme points, which are the coordinates of the boundaries of the room in which the study was made. The third elective discusses the number of levels applied. All the maps in this study use ten levels. The fourth elective discusses the value range minimum or the minimum value of the lowest level. The fifth elective discusses the value range maximum or the maximum value of the highest level.

In this study ten regular mapping symbols were used (they can be changed). For the sound pressure level (given as SIL dB) maps, a range of three dB per level was applied with the minimum and maximum value ranges depending on the particular case. For the speech perception test score contour maps five percent ranges were always used. The range minimum value was always 50 percent, and the range maximum 100 percent. (Ten levels of five percent each). The exact range of each level, for example, from 50 percent to 55 percent for the speech perception tests, is given with the maps.

The Test Results

The test results are given in Appendices A.2., A.3., and A.4.; these refer to the ambient noise in the unoccupied rooms and to the signal attenuation in those rooms (209, 312 and 402).

The speech perception test results relate to the following:

a. Differences between test lists. These tests were conducted in Room 312. The speech level was 66 dB overall, at three feet from the speaker. The ambient noise included an additional noise source of approximately NC-45, located at the rear of the room. Ten listeners participated, and six test lists were presented to the listeners.

b. The differences between female and male speakers. These tests were conducted with eleven different listeners and one male and one female test speaker. The conditions were similar to d. below. The data analysis appears in Appendix C.

c. Differences between subjects (listeners). The tests were conducted under similar conditions as described in a. However, after every test session, (reading of one test list) the listeners were "rotated" - moved by one listener location. In this way different subjects sat at the same location.

d. Presentation of the speech material in different levels. This topic was investigated in a preliminary study after which it was decided to use two presentation levels, 66 and 62 dB overall, measured at three feet from the speaker. The data presented in the Appendix refer to tests conducted in Room 312 with the two mentioned levels. At that time the ceiling was changed. The tests were conducted with the existing ambient noise in the room. Only six listeners participated.

e. The influence of additional noise. As mentioned before, noise was added in order to obtain larger signal to noise ratio differences in the rooms. The added noise was NC shaped and varied for the different tests. Tests with additional noise were conducted in Room 209. The speech level was 69 dB and the noise level NC-50; fourteen listeners participated. In Room 402, the speech level was 66 dB and the noise level NC-45; thirteen listeners participated. In Room 312, the speech level was 66 dB and the noise level NC-40; eleven listeners participated.

f. The influence of the change of absorbing ceiling. As mentioned before approximately half of the fibrous ceiling was replaced by 1/2" gypsum board panels. This was done only in Rooms 312 and 402. During the tests the speech level was 62 dB overall at three feet from the speaker, and no noise was added to the existing ambient noise.

The data presented in the contour maps are divided into two main parts: (1) Basic Acoustic Conditions, and (2) Speech Perception Test Results.

Basic Acoustic Conditions

In this section, the data are presented in the following order: Rooms 209, 312 and 402. In all cases the total range (range maximum minus range minimum) is divided into ten levels. Each level is therefore equal to 3 dB.

For the ambient noise, the range minimum is 10 dB.
the range maximum is 40 dB.

For ambient noise + NC noise, the range minimum is 20 dB.
the range maximum is 50 dB.

For broad band noise distribution, the following ranges are used:
Room 209, minimum range 52 dB, maximum range 82 dB.
Room 312, minimum range 49 dB, maximum range 79 dB.
Room 402, minimum range 52 dB, maximum range 82 dB.

Speech Perception Test Results

In this section, contour maps will be given for the speech perception test scores in percent. They are in the same order as those in the previous section.

The same ranges were applied for all the speech perception test scores (MRT scores). They are: maximum range 100 percent, minimum range 50 percent. Ten levels are used and each level is therefore equal to five percent.

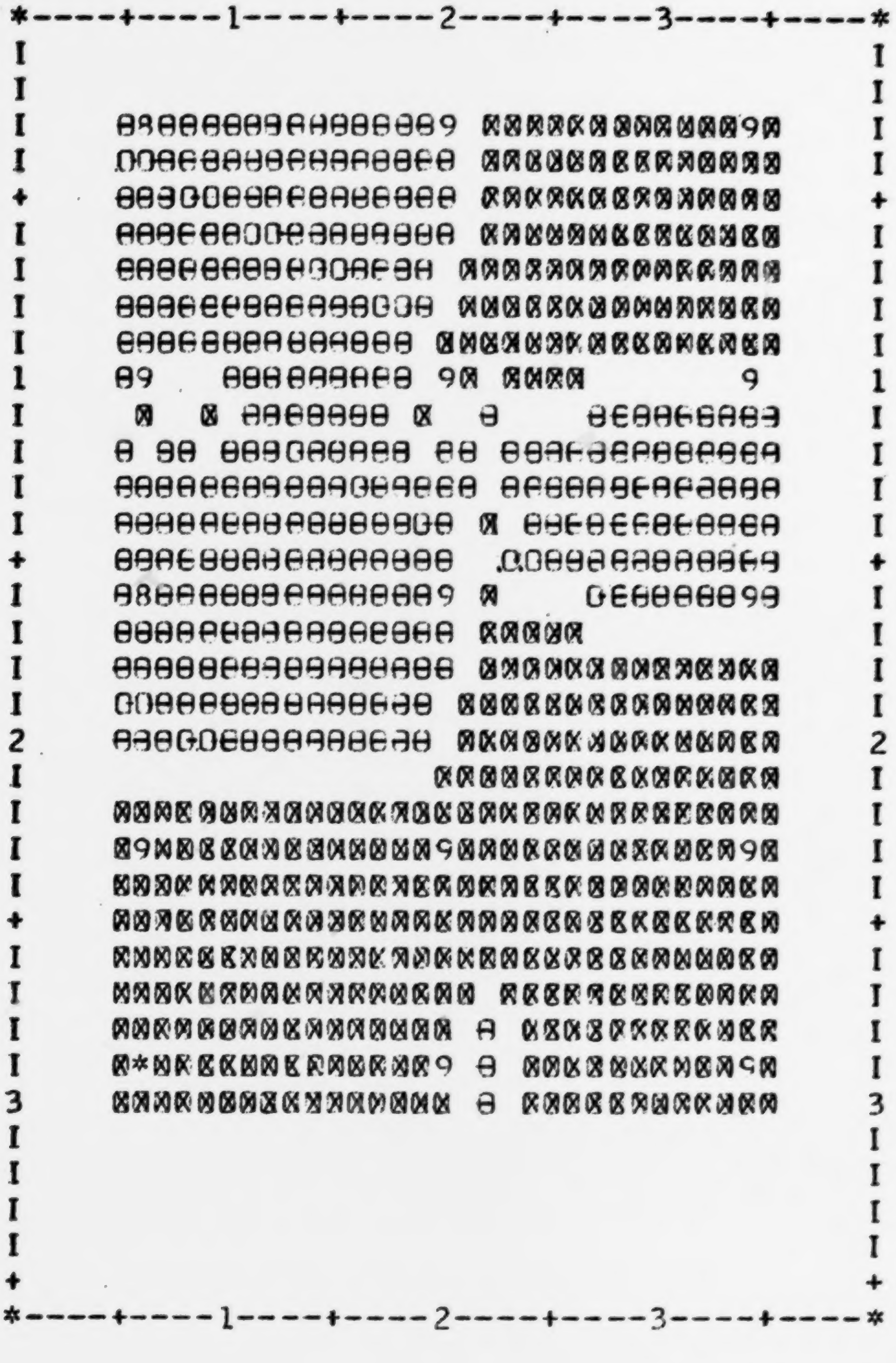
The contour maps are given in the following order:

a. Differences among subjects (see Maps 10 and 11).

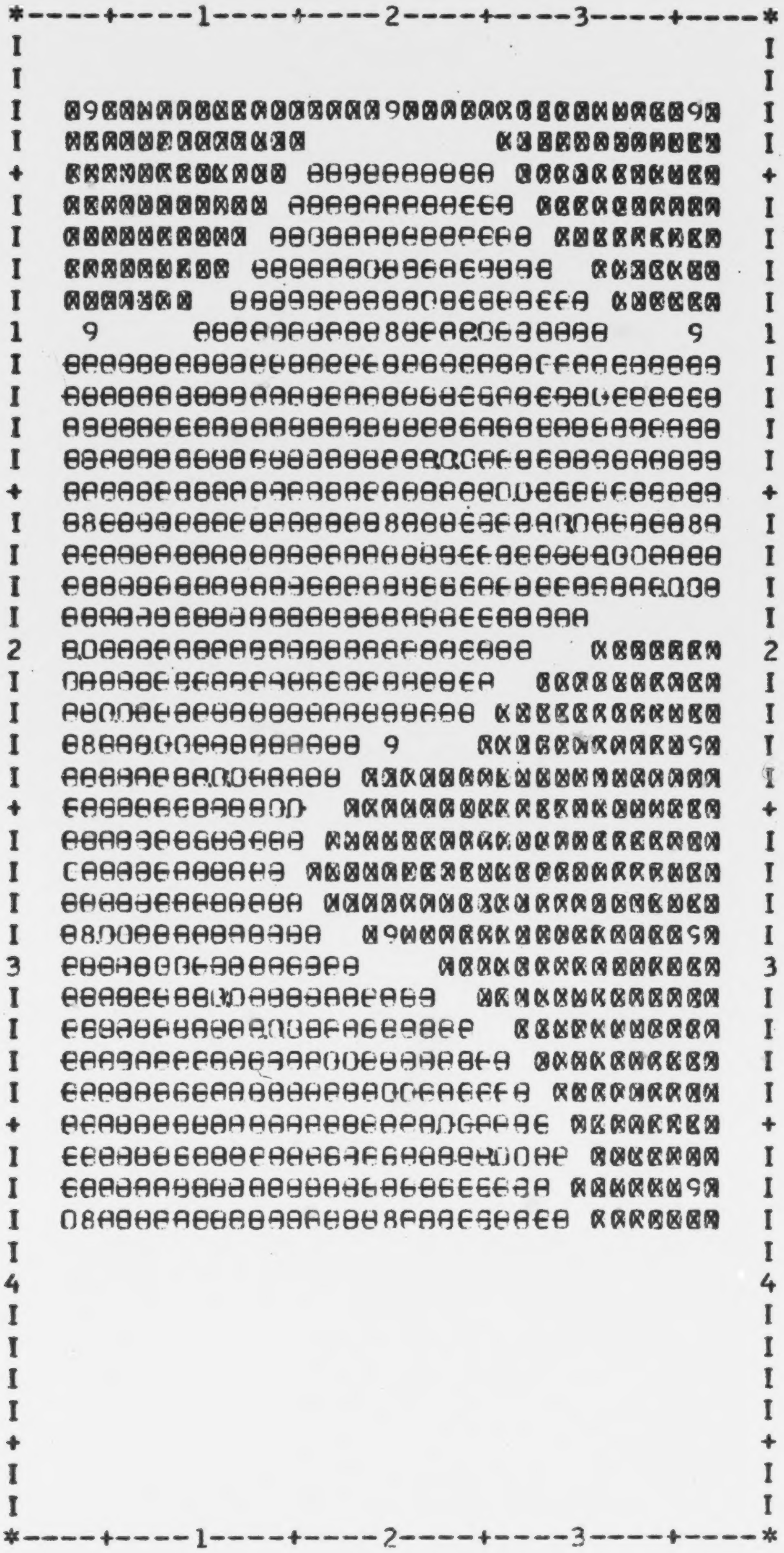
b. Presentation of speech material in different levels (see Maps 12 and 13).

c. The influence of additional noise (see Maps 10, 11, 14, 15 and 16).

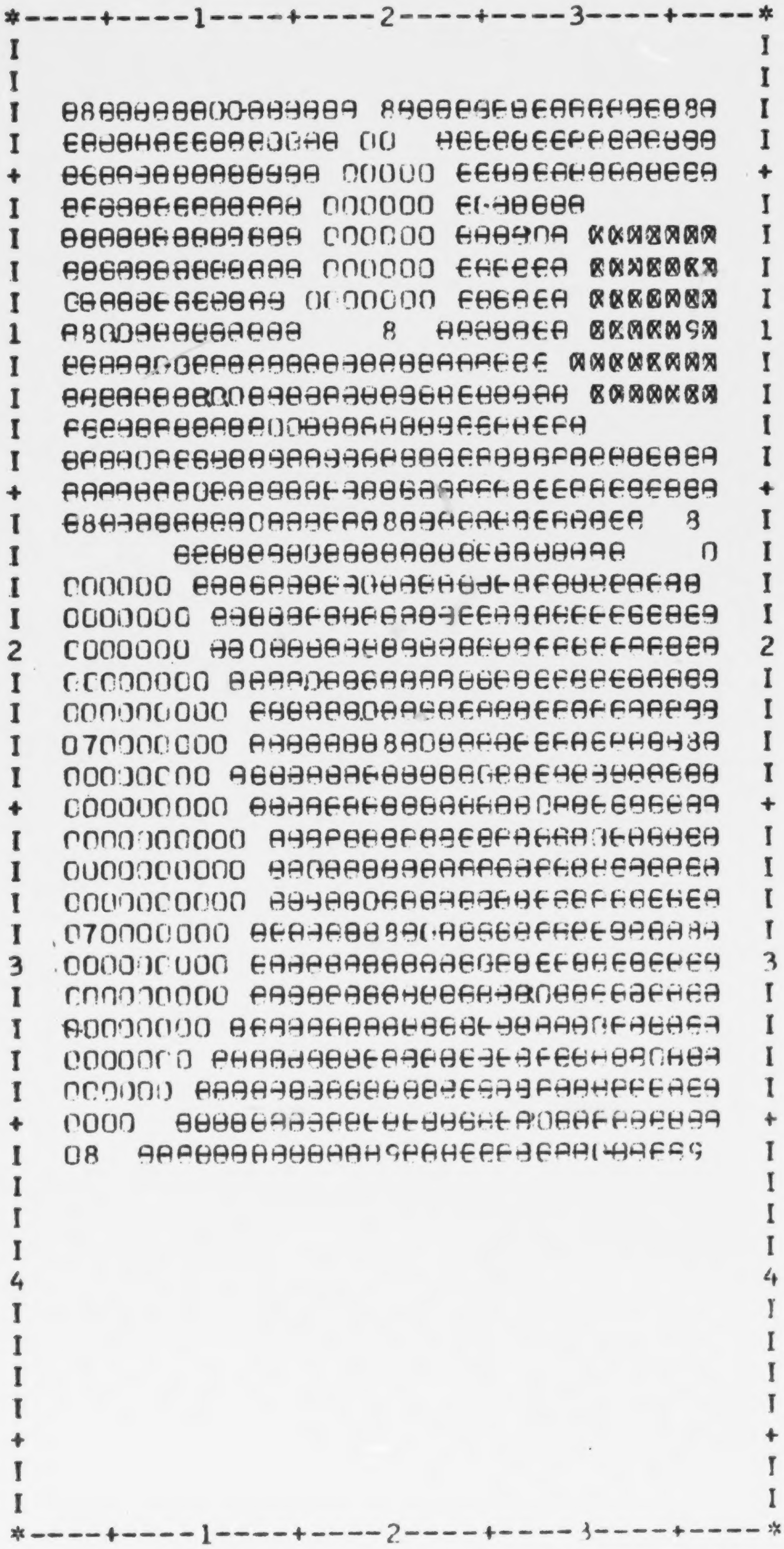
d. The influence of ceiling change (see Maps 17, 18, 19 and 20).



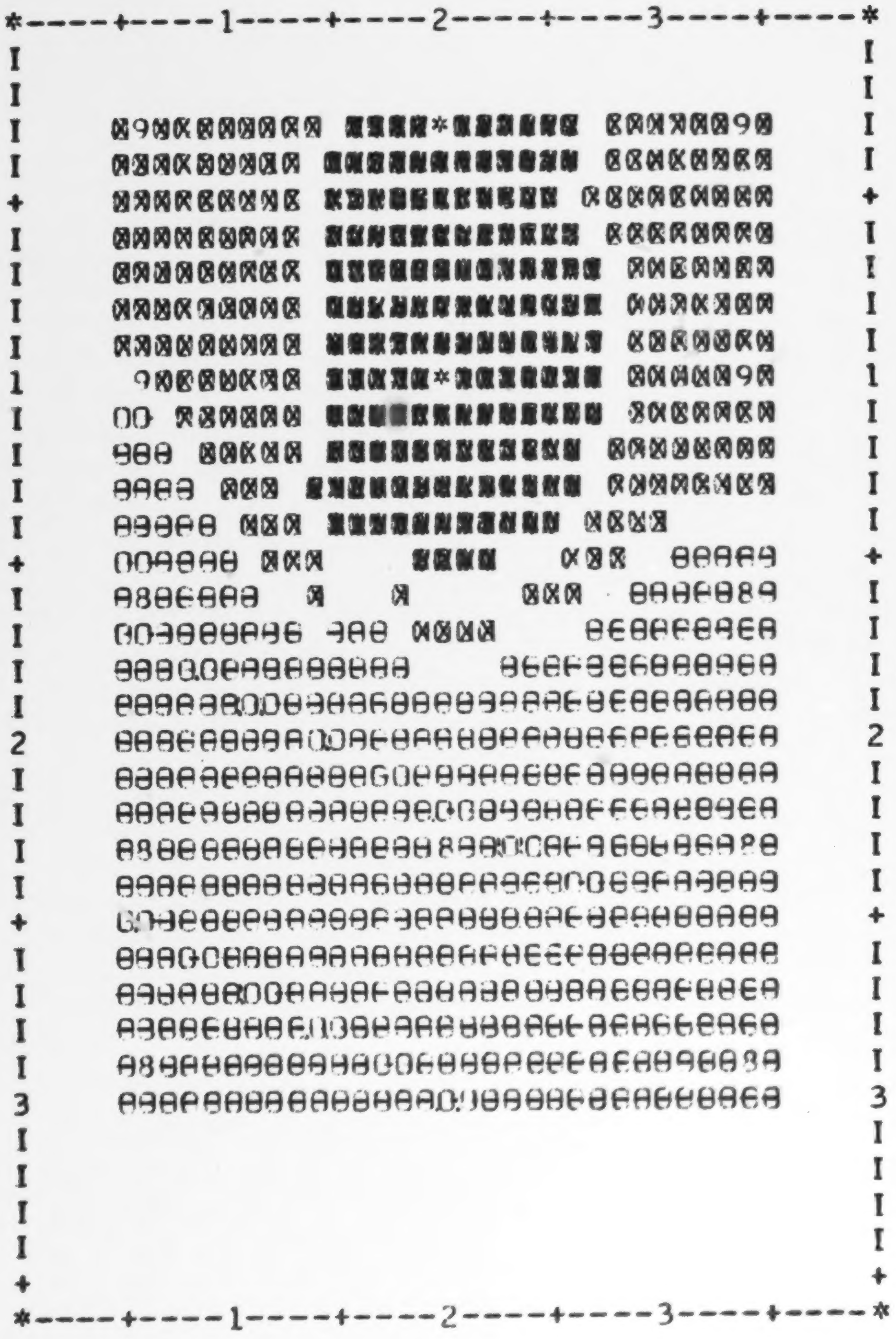
Map 1 Ambient Noise Distribution Contours, 209 Keller, Values Given in SIL dB, AAC



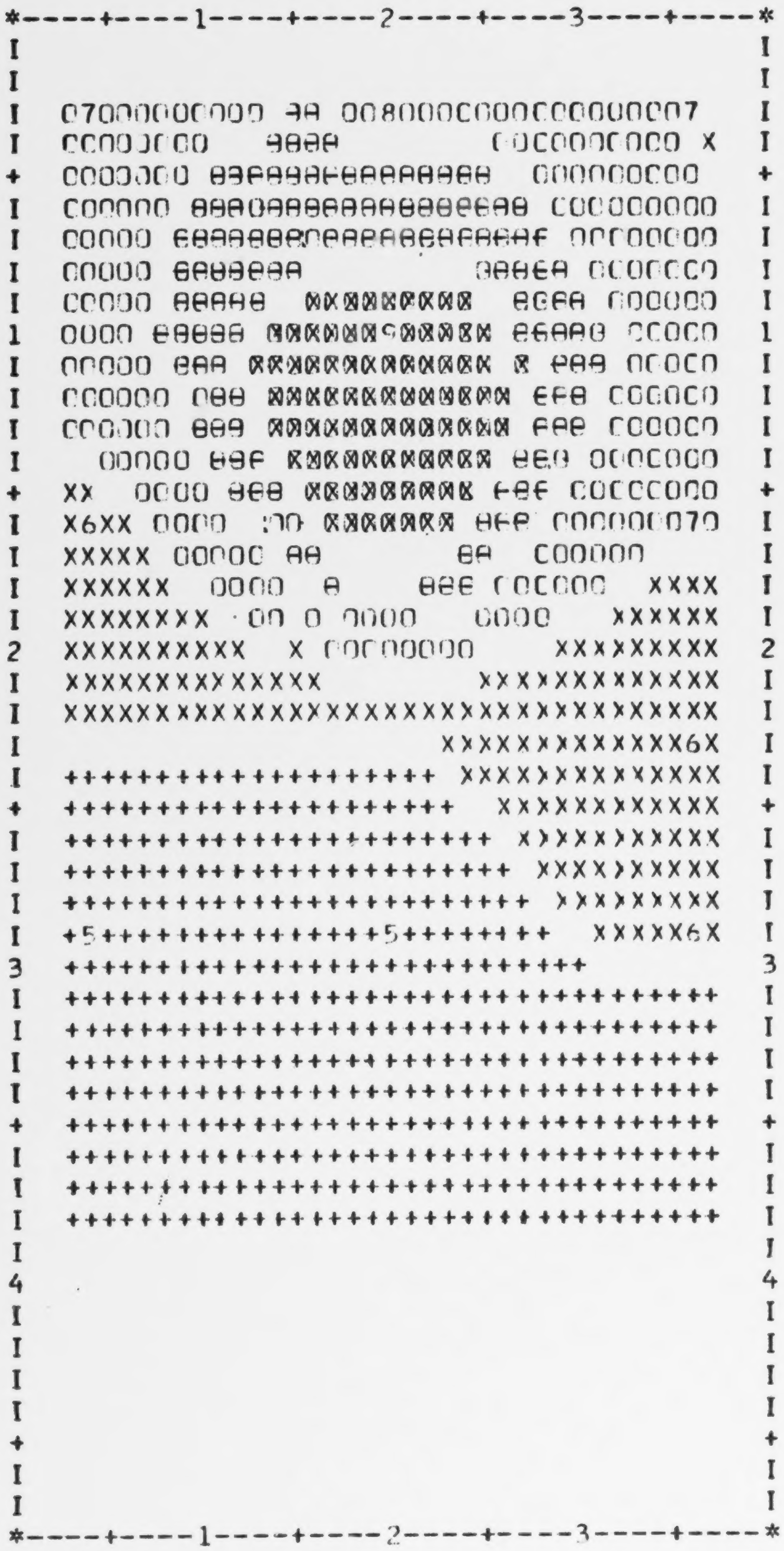
Map 2 Ambient Noise Distribution Contours, 312 Keller, Values Given in SIL dB, AAC



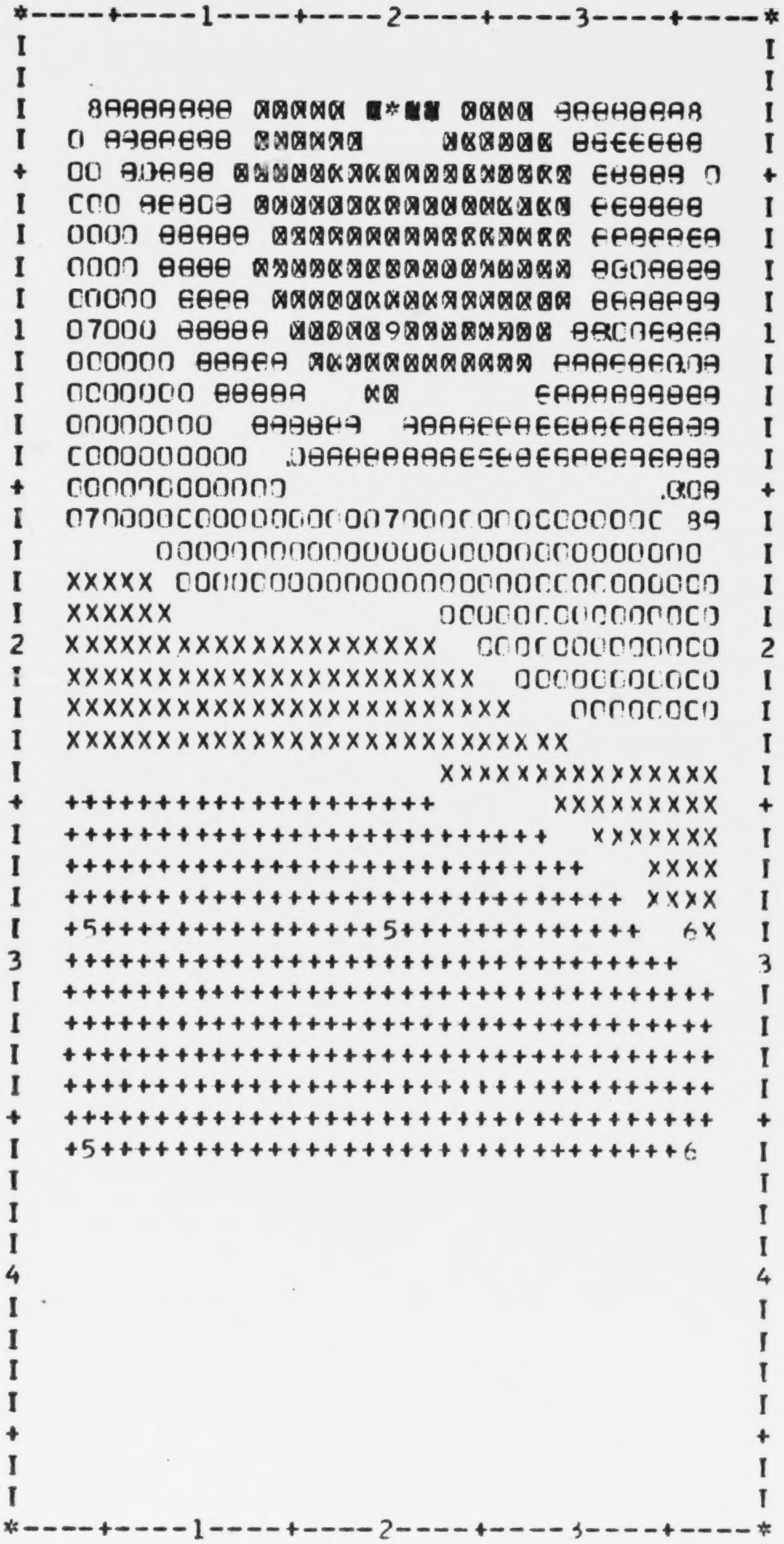
Map 3 Ambient Noise Distribution Contours, 402 Keller, Values Given in SIL dB, AAC



Map 4 Ambient Noise + NC-50 Distribution Contours, 209 Keller, 4/23, Values Given in SIL dB, AAC



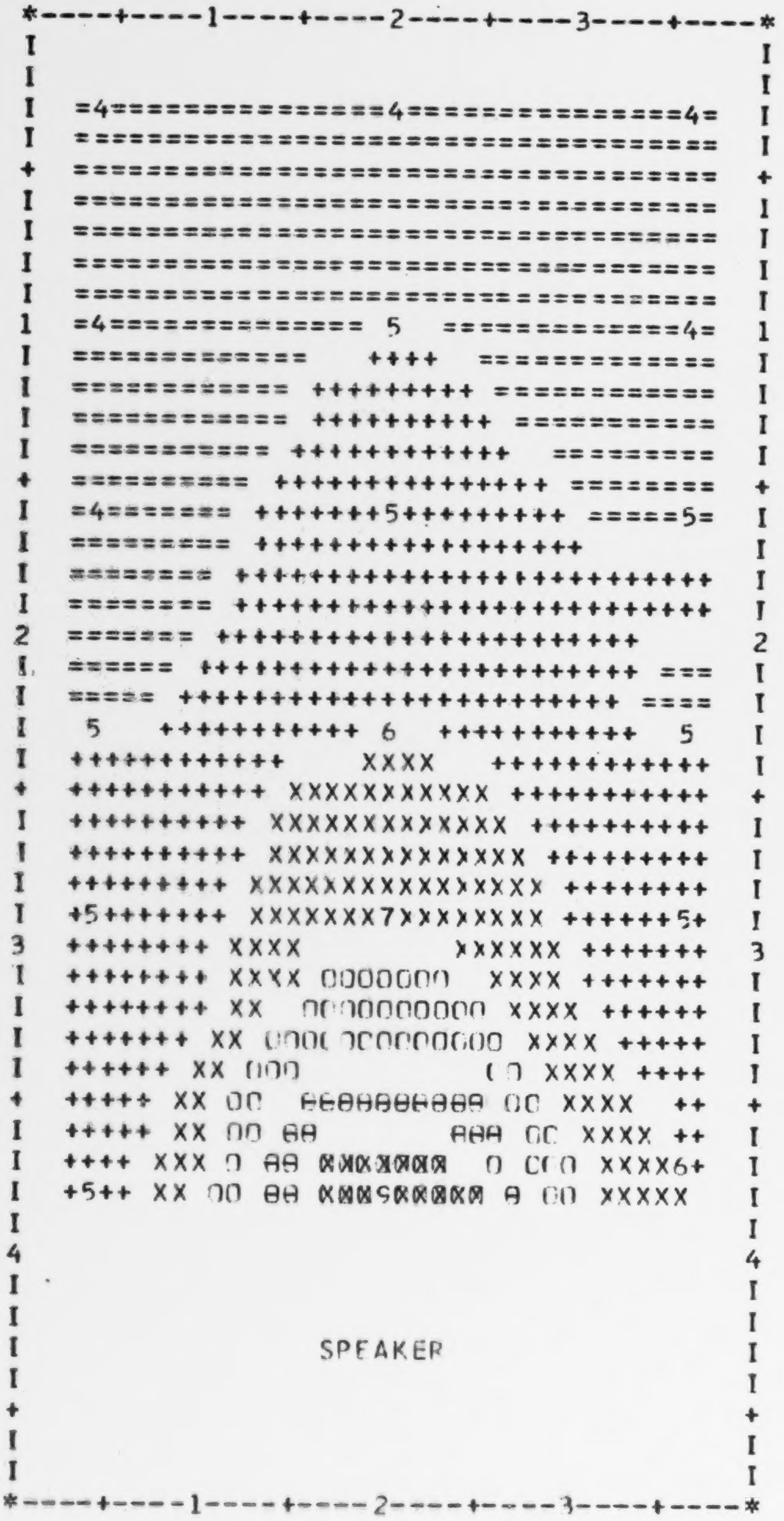
Map 5 Ambient Noise + NC-45 Distribution Contours, 312 Keller, 5/19, Values Given in SIL dB, AAC



Map 6 Ambient Noise + NC-45 Distribution Contours, 402 Keller, 4/29, Values Given in SIL dB, AAC

```
*----+----1----+----2----+----3----+----*
I                                       I
I                                       I
I    =4=============4=============4=    I
I    ===============================    I
+    ===============================    +
I    ===============================    I
I    ===============================    I
I    ===============================    I
I    ===============================    I
1    =4=============4=============4=    1
I    ===============================    I
I    ===============================    I
I    ===============================    I
I    ===============================    I
+    ==========             ========    +
I    =4======= +++++5+++++++  ====5     I
I    ======== ++++++++++++++++     +    I
I    ======== +++++++++++++++++++++     I
I    ======= ++++++++++++++++++    =    I
2    ======= ++++++    ++++++++ ====    2
I    ====== ++++   XXXX  +++++ =====    I
I    ====== +++ XXXXXXXXX ++++ =====    I
I    =4==== +++ XXXX6XXXX ++++ ===4=    I
I    ====== ++ XXXXXXXXXXX +++ =====    I
+    ====== ++ XX       XX +++ =====    +
I    ====== + XX 0000000 XX + ======    I
I    ====== + X 000000000 XX + =====    I
I    ===== ++ X 00     00 XX ++ ====    I
I    =4=== + X 0  88888 00  +++ ==4=    I
3    ===== + X 0 8808888 00  ++ ====    3
I                                       I
I                                       I
I                SPEAKER                I
I                                       I
+                                       +
*----+----1----+----2----+----3----+----*
```

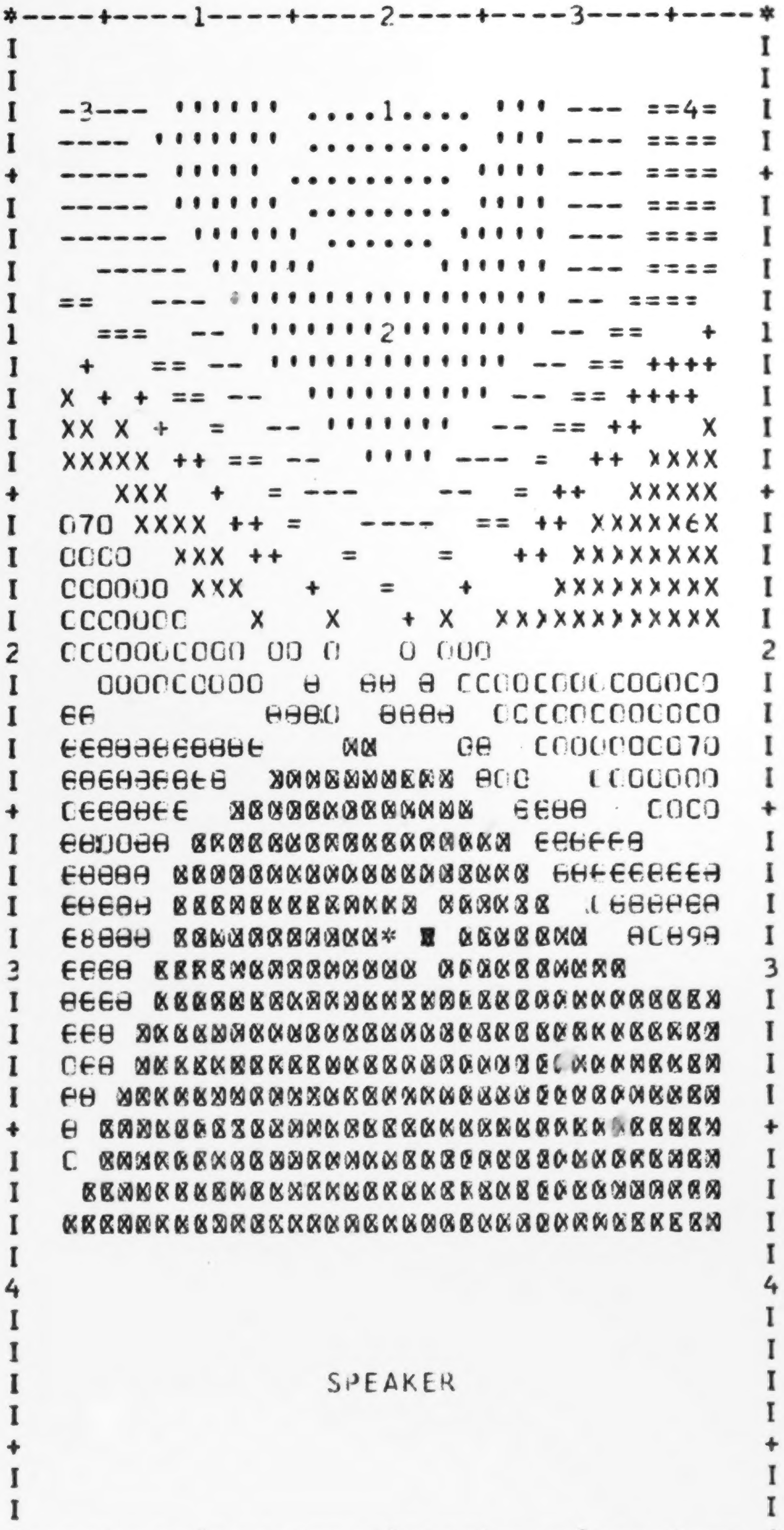
Map 7 Broad Band Noise Distribution Contours, 209 Keller, Values Given in SIL dB, 75 SIL dB 3 feet from Speaker, AAC


1
2
3
4
5
6
7
9
SPEAKER

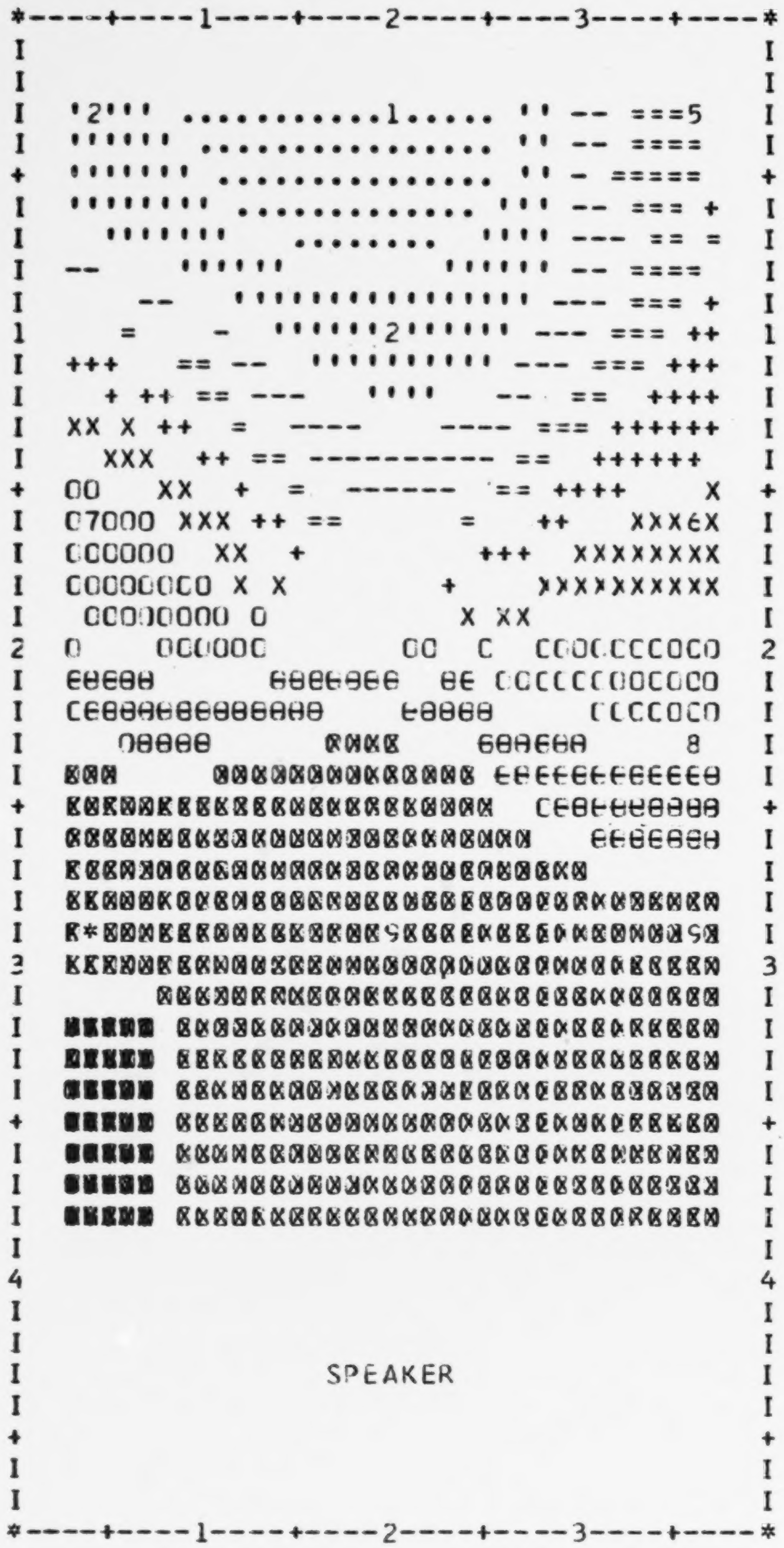
Map 8 Broad Band Noise Distribution Contours, 312 Keller, Values Given in SIL dB, 79 SIL dB 3 feet from Speaker, AAC

```
*----+----1----+----2----+----3----+----*
I                                       I
I                                       I
I  -3---------------3---------------3-  I
I  -----------------------------------  I
+  -----------------------------------  +
I  -----------------------------------  I
I  -----------------------------------  I
I  -----------------------------------  I
I  -----------------------------------  I
1  -3-------------  4  -------------3-  1
I  ------------   =====   ------------  I
I  ----------- =========== -----------  I
I  ---------- ============ -----------  I
I  --------- ============== ----------  I
+  -------  =============== ----------  +
I  -4---  ==========4======= -------3-  I
I       ==================== ---------  I
I  ========================== --------  I
I  =========================== -------  I
2  ============================         2
I  ===================================  I
I  ===================================  I
I  =4===========    5  =============4=  I
I  ==========   +++++++    ===========  I
+  ========= ++++++++++++++ ==========  +
I  ======== ++++++++++++++++  ========  I
I  ======== ++++++++++++++++++ =======  I
I  ======== ++++++++++ ++++++++ ======  I
I  =4===== ++++     6 X   ++++++  ==5=  I
3  ======= +++ XXXXXXXXXXX  ++++++      3
I  ====== +++ XXXXXXXXXXXXX ++++++++++  I
I  ===== +++ XXX          XX +++++++++  I
I       +++ XX OOOOOOOOOOO XX ++++++++  I
I  ++++++++ X OOOOOOOOOOOOO XX +++++++  I
+  +++++++ XX OO         OOO XX ++++++  +
I  +5++++ XXX O 888888888 OO XX ++++5+  I
I                                       I
I                                       I
I                                       I
4                                       4
I                                       I
I                                       I
I               SPEAKER                 I
I                                       I
+                                       +
I                                       I
I                                       I
*----+----1----+----2----+----3----+----*
```

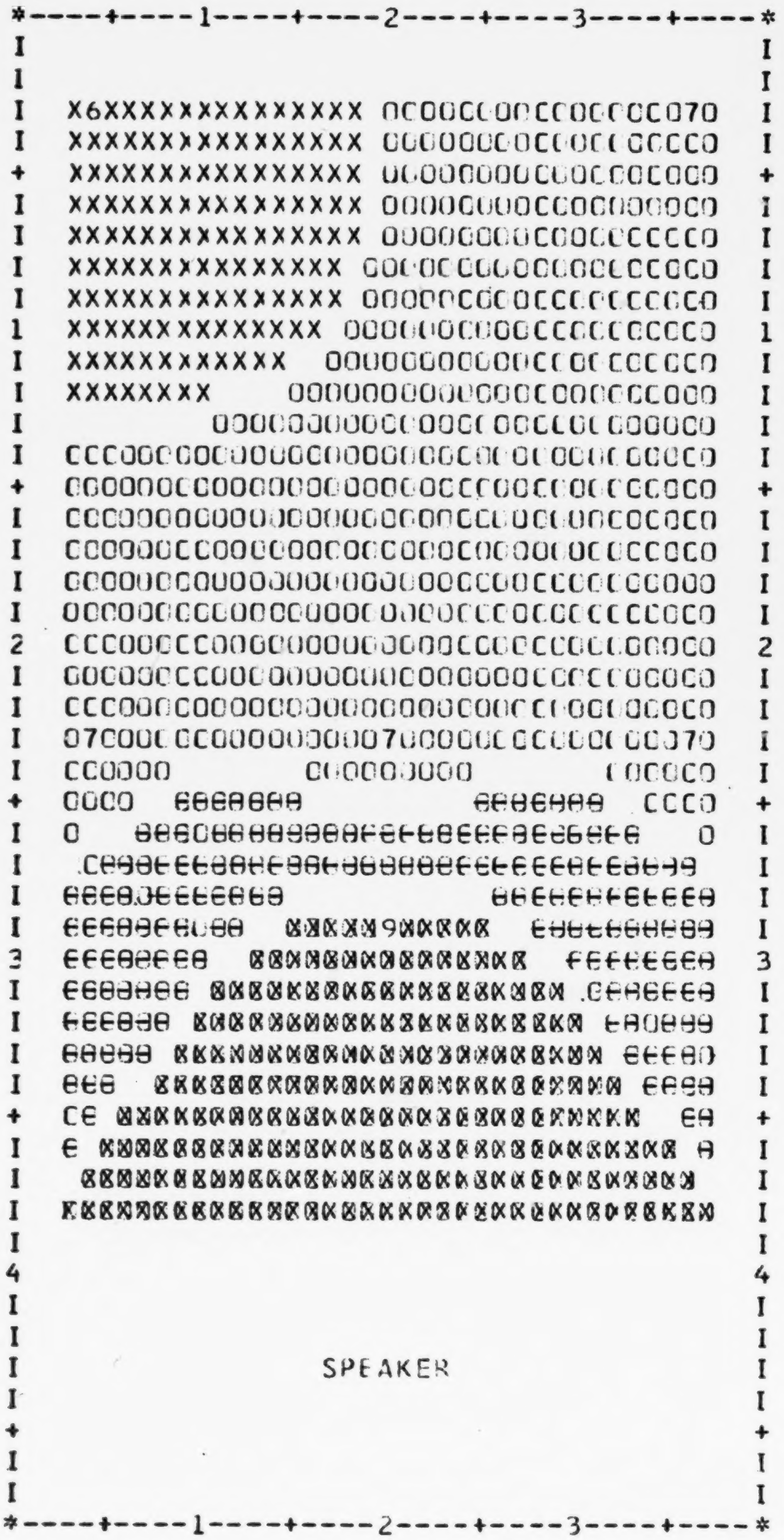
Map 9 Broad Band Noise Distribution Contours, 402 Keller, Values Given in SIL dB, 82 SIL dB 3 feet from Speaker, AAC



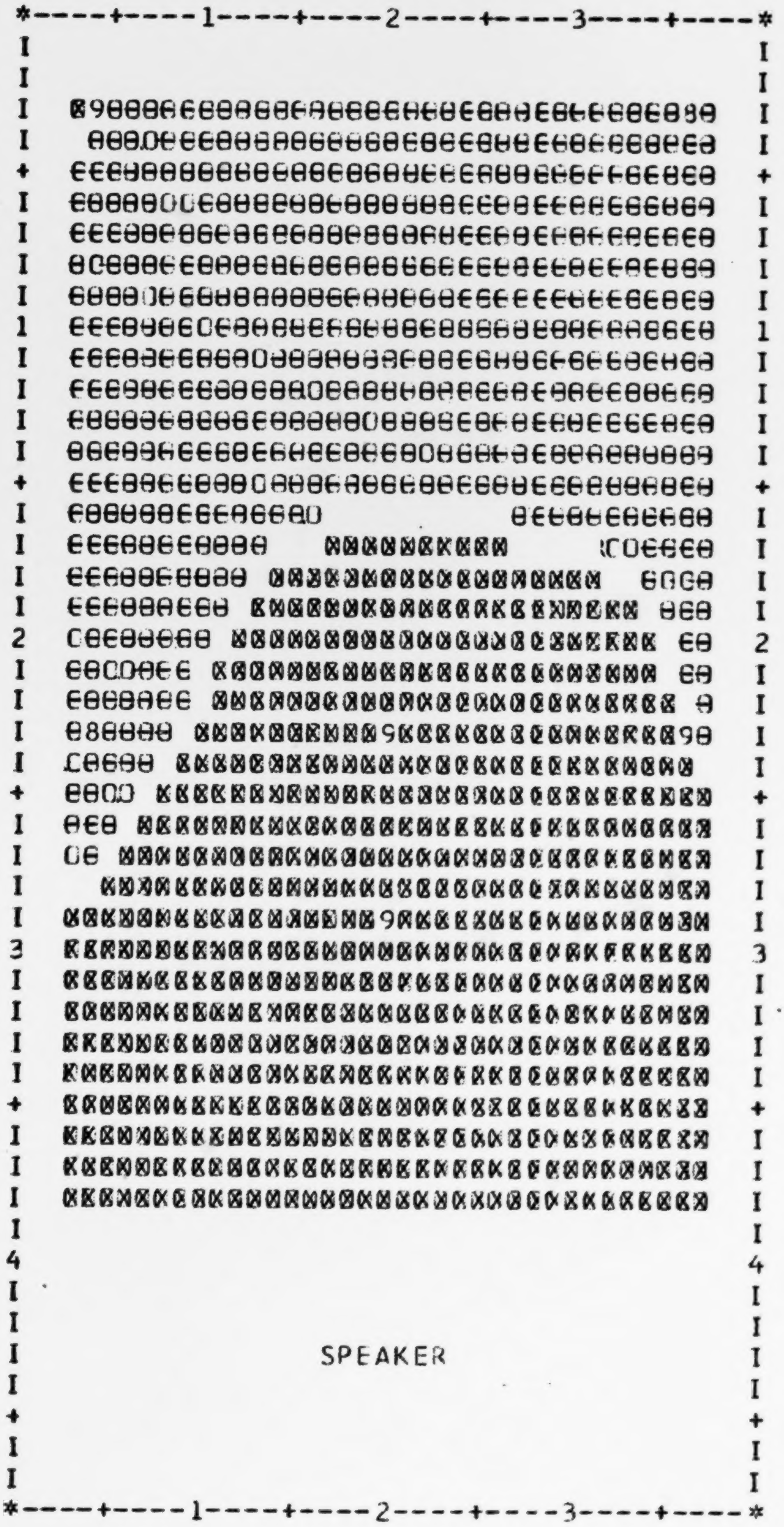
Map 10 MRT Score Contours, 312 Keller, 10 Subjects, 5/19, Speech Level 66 dB Overall 3 feet from Speaker, Ambient Noise + NC-45, AAC



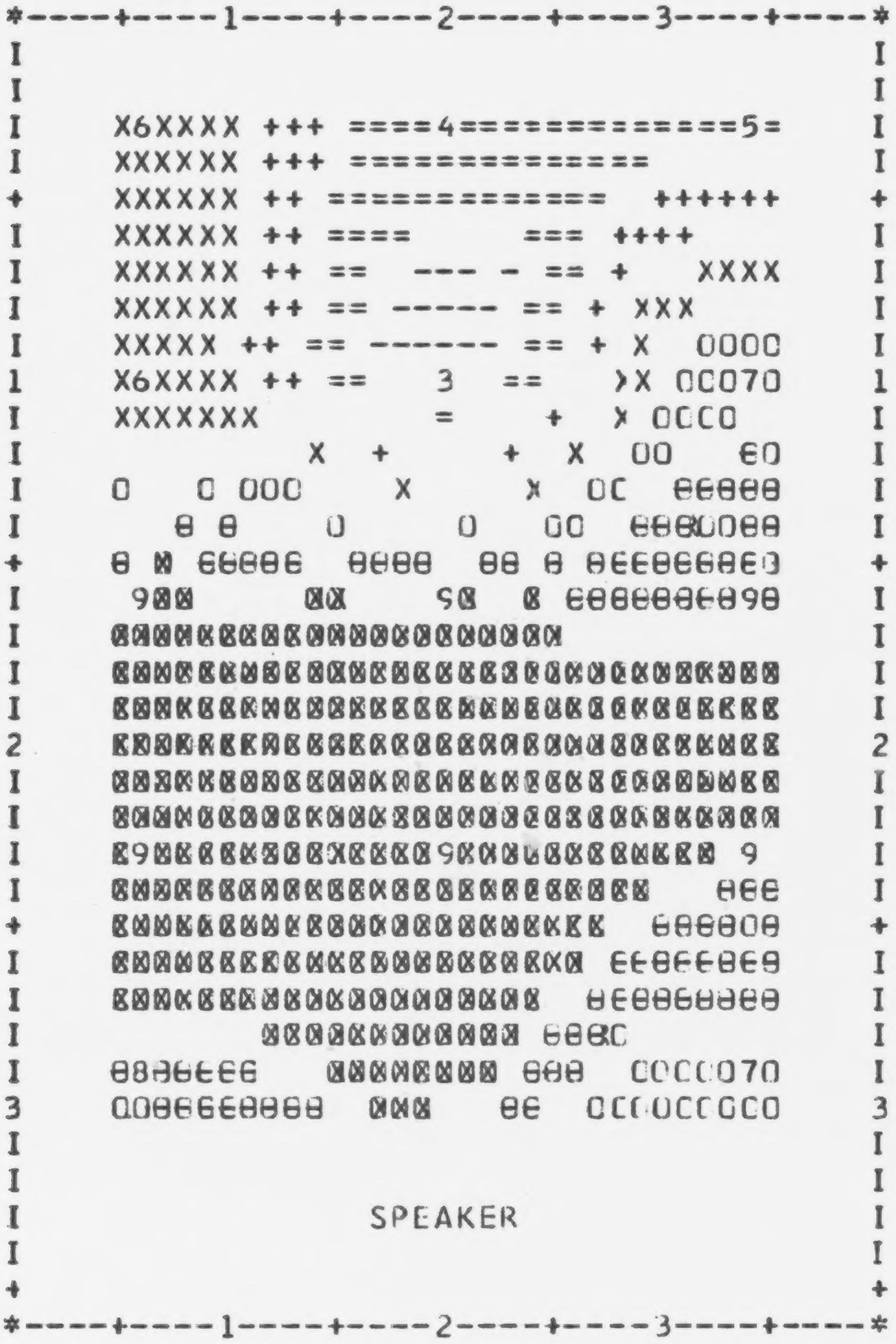
Map 11 MRT Score Contours, 312 Keller, 10 Subjects, 5/19, Speech Level 66 dB Overall 3 feet from Speaker, Ambient Noise + NC-45, AAC



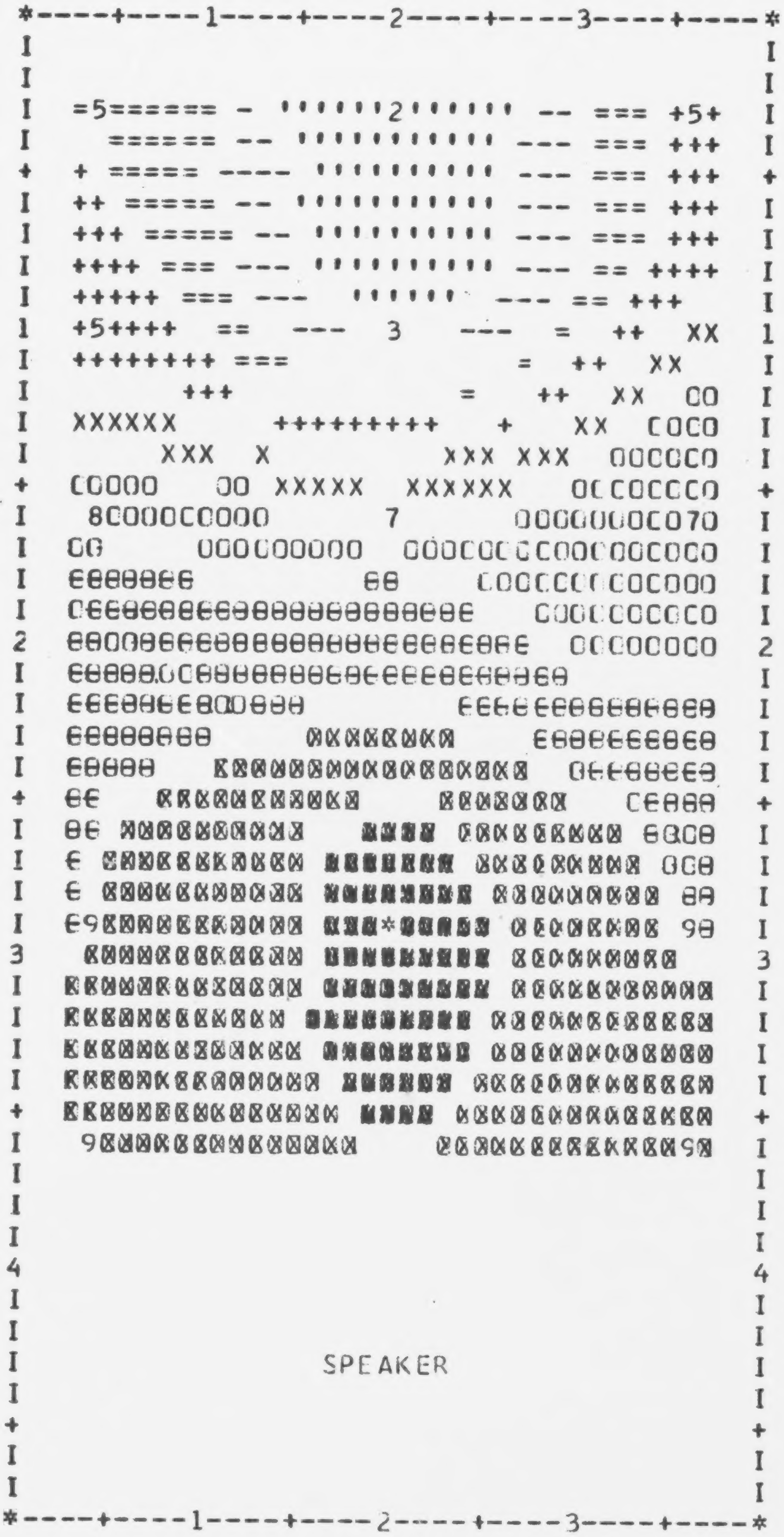
Map 12 MRT Score Contours, 312 Keller, 6 Subjects, 5/22, Speech Level 62 dB Overall 3 feet from Speaker, Ambient Noise Only, GBC, SIL S/N = 52/34



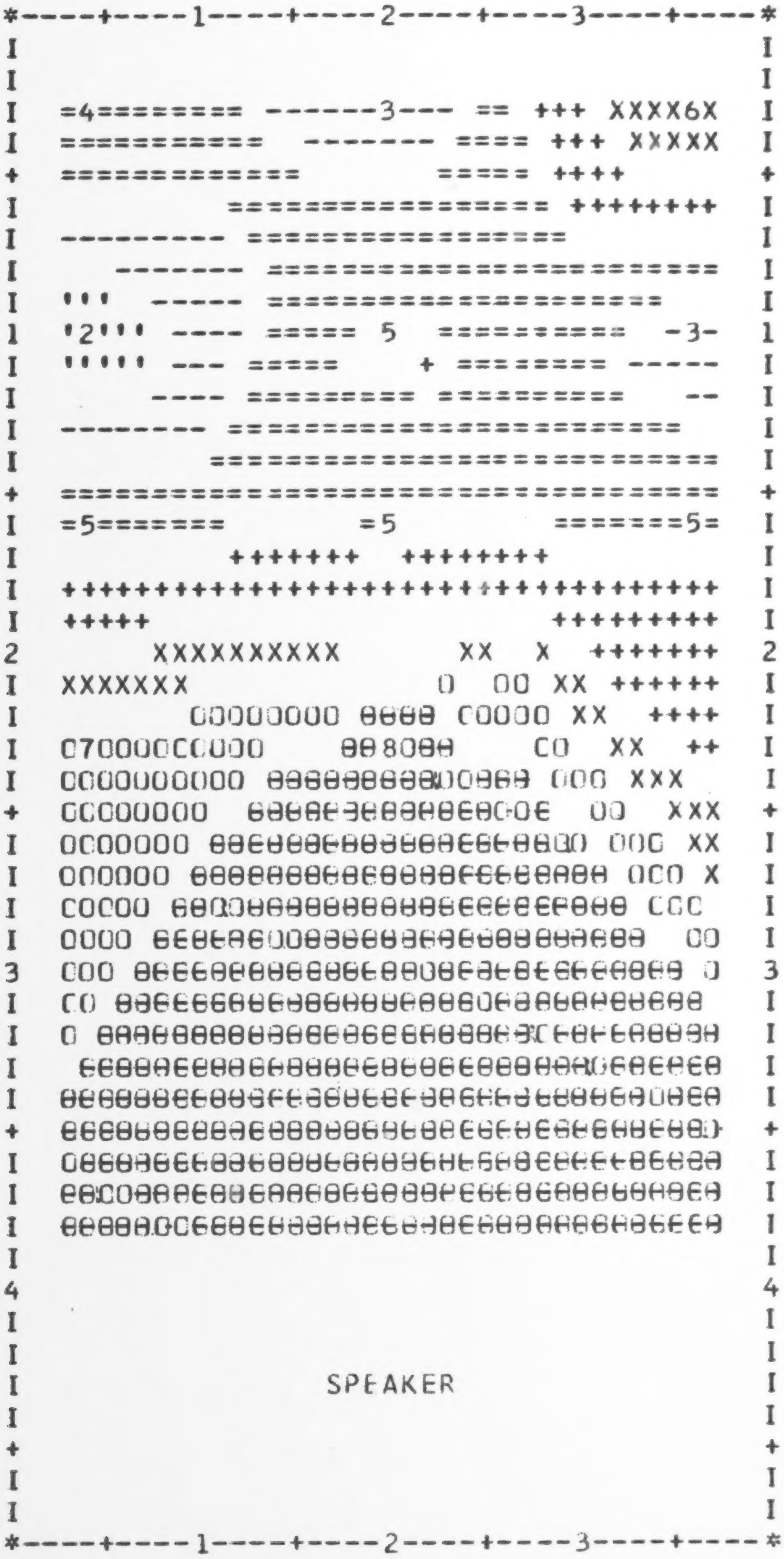
Map 13 MRT Score Contours, 312 Keller, 6 Subjects, 5/22, Speech Level 66 dB Overall 3 feet from Speaker, Ambient Noise Only, GBC, SIL S/N = 56/34



Map 14 MRT Score Contours, 209 Keller, 14 Subjects, 4/23, Speech Level 69 dB Overall 3 feet from Speaker, Ambient Noise + NC-50, AAC



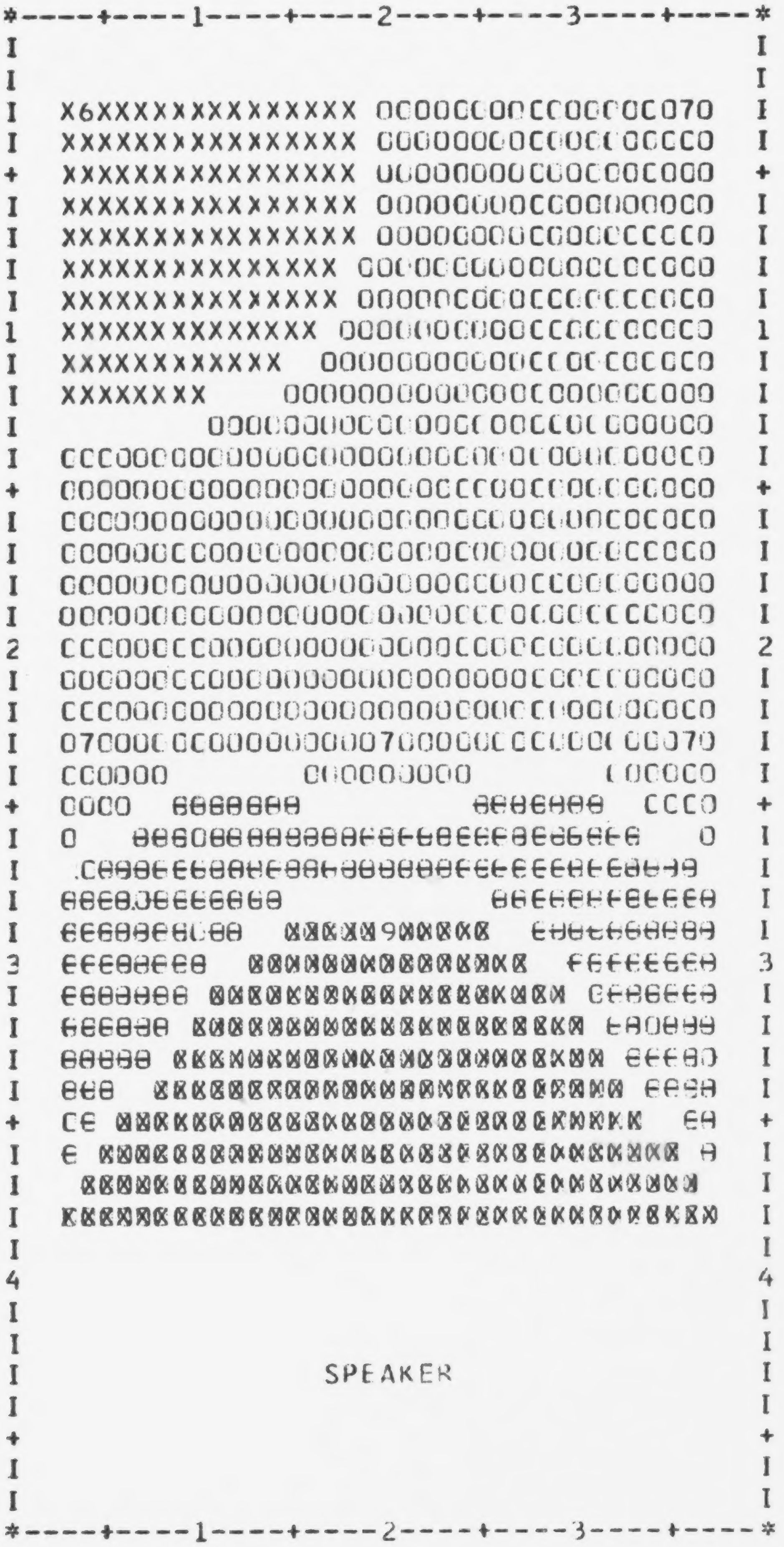
Map 15 MRT Score Contours, 402 Keller, 13 Subjects, 4/29, Speech Level 66 dB Overall 3 feet from Speaker, Ambient Noise + NC-45, AAC


1
2
3
4
5
6
SPEAKER

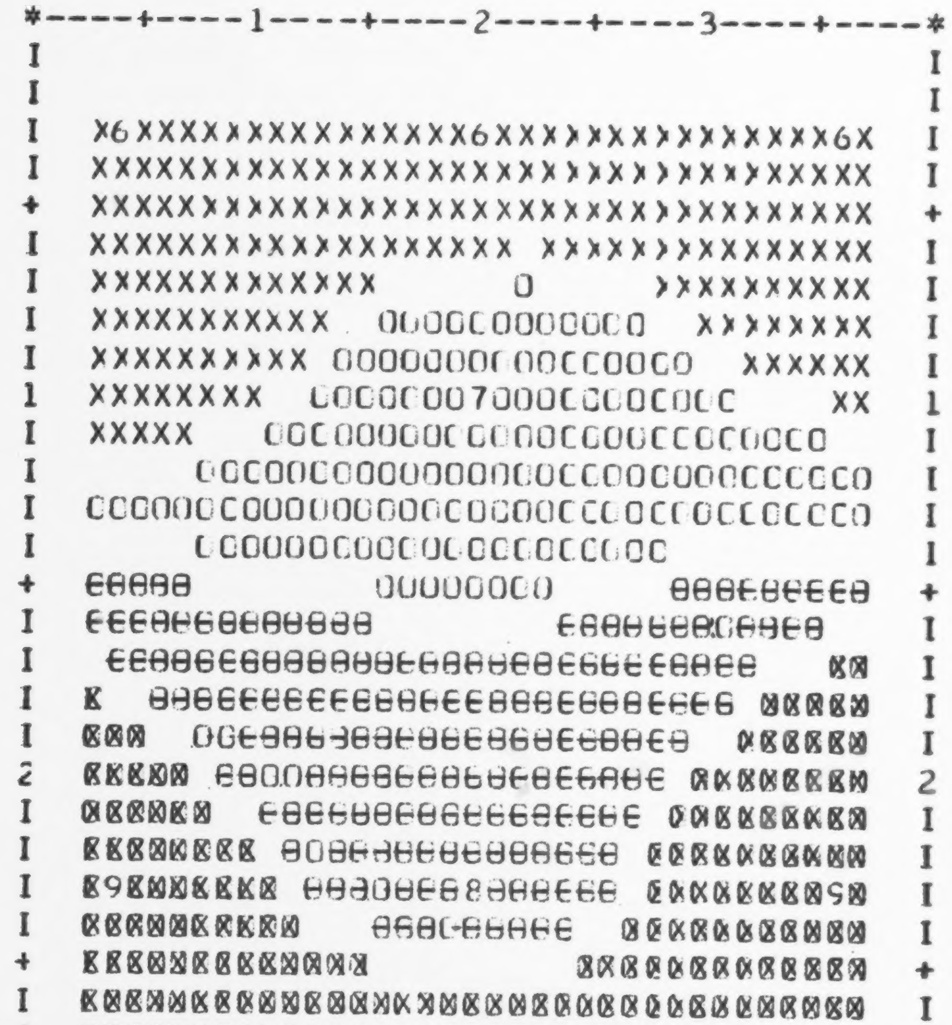
Map 16 MRT Score Contours, 312 Keller, 11 Subjects, 4/30, Speech Level 66 dB Overall 3 feet from Speaker, Ambient Noise + NC-40, AAC

```
*----+----1----+----2----+----3----+----*
I                                       I
I                                       I
I  +5++++++ XXXXXXX 700000 XXXXXXXX 70  I
I  ++++++++ XXXXXXXX      XXXXXXXXXX    I
+  ++++++++ XXXXXXXXXXXXXXXXXXXXXXXXXX  +
I  ++++++++ XXXXXXXXXXXXXXXXXXXXXXXXXX  I
I  +++++++ XXXXXXXXXXXXXXXXXXXXXXXXXXX  I
I  ++++++++ XXXXXXXXXXXXXXXXXXXXXXXXXX  I
I  ++++++++ XXXXXXXXXXXXXXXXXXXXXXXXXX  I
1  +++++++++ XXXXX   6XXXXXXXXXXXXXXXX  1
I  ++++++++++    +++    XXXXXXXXXXXXXX  I
I  ++++    +++++++++++++  XXXXXXXXXXXX  I
I      XXXX  +++++++++++++ XXXXXXXXXXX  I
I  XXXXXXXXXX ++++++++++++  XXXXXXXXXX  I
+  XXXXXXXXXXXX ++++++++++++ XXXXXXXXX  +
I   XXXXXXXXXXXX    +++++++ XXXXXXXXXX  I
I  0   XXXXXXXXXXXX        XXXXXXXXXXX  I
I  COCO XXXXXXXXXXXXXXXXXXXXXXXXXXXXXX  I
I  COOOO XXXXXXXXXXXXXXXXXXXXXXXXXXXXX  I
2  COOOOO XXXXXXXXXXXXXXXXXXXXXXXXXXXX  2
I  CCCOOOC XXXXXXXXXXXXXXXXXXXXXXXXXXX  I
I  OOOOOOCO XXXXXXXXXXXXXXXXXXXXXXXXXX  I
I  C7OOOOOOO XXXXXXX6XXXXXXXXXXXXXXX6X  I
I  CCOOOOOOOO XXXXXXXXXXXXXXXXXXXXXXXX  I
+  COOOOOCOOOO  XXXXXXXXXXXXXXXXXXXXXX  +
I  COOOOOCCOOOOOO        XXXXXXXXXXXXX  I
I  OOOOOOCOOOOOOOOOOOCOOOOO XXXXXXXXXX  I
I  CCCOJOCCOOOOOOOOOOOCCOCOO  XXXXXXXX  I
I  CCOOOOCOOOOOOOOOOO7OOOOOOCO   XXXXX  I
3  CCOOOOOCOOOOOOOOOOOOOOCOOOCOOCO XXX  3
I  CCCOOOCCOOOOOOOCOCOOOCOOOCCOOOOO     I
I  COOOOOCCOOOOOOOOCOOOOOOOOOOOCCCCOCO  I
I  COOOOCCOOOCOOOOOOCCCCCCOOCCOCCCCCCO  I
I  OCOOOOOCOOOOOOOOOOOOOOCOOOCCCCCCOCO  I
+  OCCOOCCCOOOOOOOOOOOOOCCOOCCOOCOCCCO  +
I  COOOOOCCOOCOOOOOOOOOOOCOOOCCCCCCOCO  I
I  CCCOOOCCOOOOOOOOOOOOOCOCOCCCCCOCO70  I
I  COCOOOCCOOOOOOCOOCOOOOCOOCCOOOOCCCO  I
I                                       I
4                                       4
I                                       I
I                                       I
I               SPEAKER                 I
I                                       I
+                                       +
I                                       I
I                                       I
*----+----1----+----2----+----3----+----*
```

Map 17 MRT Score Contours, 312 Keller, 9 Subjects, 5/28, Speech Level 62 dB Overall 3 feet from Speaker, Ambient Noise Only, AAC, SIL S/N = 52/34



Map 18 MRT Score Contours, 312 Keller, 6 Subjects, 5/22, Speech Level 62 dB Overall 3 feet from Speaker, Ambient Noise Only, GBC, SIL S/N = 52/34



Map 19 MRT Score Contours, 402 Keller, 9 Subjects, 5/26, Speech Level 62 dB Overall 3 feet from Speaker, Ambient Noise Only, AAC, SIL S/N = 52/32

```
*----+----1----+----2----+----3----+----*
I                                       I
I                                       I
I  +5++ XXXX C0000C07CCCC000C0C0000C070 I
I  ++++ XXXXX 000C00C000C000CC0CCCCCC0  I
+  ++++ XXXXXX 0000000000C000CCCCCCCC0  +
I  +++ XXXXXX 00000C0C0CCC0CCCCCC0C0C0  I
I  +++ XXXXXXX 00000000C000CC0CC0CCCC0  I
I  ++ XXXXXXXXX  00C000C000C00C000C0    I
I  ++ XXXXXXXXXXX        0000C00C00CCC0 I
1    XXXXXXXXXXXXXXX6XXX  0 CC0CCCCCC0  1
I  XXXXXXXXXXXXXXXXXXXXXXXX X C0000000  I
I  XXXXXXXXXXXXXXXXXXXXXXXXX CCCCCCCCC0 I
I  XXXXXXXXXXXXXXXXXXXXXXXXX CC0C000C   I
I           XXXXXXXXXXXXX  0C000000  Θ  I
+  CC000000C0    XXXXXX    00C00000 ΘΘΘ +
I  CC000C000000        00C000000  €€ΘΘ0 I
I  00C00000000C000C00000C00CC0 €€ΘΘΘΘ   I
I  CCC00000000C0CCC000C000   ΘΘ0CΘΘ€Θ   I
I  CC00CCC000000000C000CC  €€Θ€€€€00    I
2  CC000000C0C000000C000 €Θ€€€Θ€€€ΘΘΘ   2
I  0C000000000C0000000C00  Θ0·0€€€€€ΘΘ€ I
I  C00      CCC00000CC00 €ΘΘΘ€C0ΘΘΘΘΘΘ  I
I  C8 ΘΘΘΘΘ         08  ΘΘΘΘΘΘΘΘ0C€Θ90  I
I   ΘΘΘ€€€ΘΘΘΘΘΘΘΘ ΘΘΘΘ€ΘΘΘ€€€€€€0C    I
+  C€€ΘΘ€€€€ΘΘ€ΘΘ€ΘΘ€€€ΘΘ€€€€ΘΘ€€ΘΘ€€ΘΘ€ +
I  ΘΘ00ΘΘ€€€ΘΘΘΘΘ€ΘΘΘΘΘ€€€Θ€€€€€€ΘΘ€Θ   I
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3  €€ΘΘΘ€€€ΘΘΘΘΘΘ00ΘΘΘ€ΘΘ€€ΘΘΘΘ€ΘΘ€€€ΘΘ€Θ 3
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I                                       I
I                                       I
I                                       I
4                                       4
I                                       I
I                                       I
I               SPEAKER                 I
I                                       I
+                                       +
I                                       I
I                                       I
*----+----1----+----2----+----3----+----*
```

Map 20 MRT Score Contours, 402 Keller, 9 Subjects, 5/28,
Speech Level 62 dB 3 feet from Speaker,
Ambient Noise Only, GBC, SIL S/N = 52/32

The Analysis of the Speech Perception Test Results

The data obtained in the speech perception tests described above contain several variables which may have influenced the test results. Human subjects are involved and, therefore, such factors as learning, fatigue, degree of interest, motivation, and other subjective factors may influence the test score. The Modified Rhyme Test's construction assumes that the different test lists are similar in difficulty, and that the order of testing is unimportant. Other variables, such as room characteristics are incorporated in the tests themselves. These include reproduction level and added noise.

The data analysis is for the various variables that are possible, or were added in the testing program. The analysis basically is an analysis of variance. This analysis tests the variance among the test lists means for a particular test, and is the recommended method for analysis of intelligibility scores. The reason is that since human subjects are involved, the test scores are somewhat variable, even if the test conditions are the same. This method is an accurate tool to find whether those differences are significant or chance.

The analysis of variance assumes that the sample distribution is normal, or close to it. The frequency distribution of speech perception test scores was found (Beranek, 1949) to be close to normal, unless the mean score is very high or very low. Data given in Appendix C. 1. show the plotted frequency distribution of the speech perception test scores as obtained in Room 209. It is seen that despite the relatively limited amount of data given, the distribution tends to form the normal shape.

The order of test list presentation in testing speech perception (which list first) should be of no importance. This was tested by checking the correlation between test lists. This analysis is further discussed in Appendix C. 2.

So far it has been found that the speech perception test results have a normal distribution, and that under most circumstances a positive correlation between the test lists exists. These two points still do not answer the question of whether the test lists are significantly different. This is tested in two ways: the first investigates the test variances among the mean performances of subjects for the different test lists (see column of means in table of correlation tests, Appendix D. 2. , and the second examines the variances among the means of experimental subjects (listeners) seated at different locations.

If, in addition to the difference among the test lists, the influence of the seating location on the speech perception test score is tested, the following hypothesis can be made: the differences among the variances (of the scores) of the test lists should be small enough to be considered as drawn from one population. On the other hand, the differences among the variances of the scores for the locations should be large so that they can be considered as significantly different. If this is true, then the different test lists do not differ significantly from one another, while the location does, and, therefore, has a significant influence on the speech perception test score.

To test the above hypothesis a computer library program of "Analysis Of Variance with Repeated Measures" (AOVRM) was used for the various cases (different test lists, different rooms, with and without additional noise and after ceiling change). Table II summarizes the analysis of variance tests and Appendix D. 3. includes a numerical example of a one way analysis of variance with repeated measures on one factor. From Table II it can be seen that the differences "between subjects" have, in all cases F ratios that are larger than the critical five percent value. In most cases, the values are even higher than the critical one percent value. All F ratios, therefore, are significant at the five percent level. In other words, differences of the magnitudes obtained would occur much less than five percent of the time because of chance only.

For the "Between tests", (in the same table) it can be seen that in three cases (1, 2 and 4), none of the F ratios were significant at the five percent level. On the other hand, in the three other cases (3, 5 and 6) the F ratios are larger than the critical five percent value. Thus, it can be said that in the first three cases there are no significant differences among the test lists, while in the later three there are. An explanation for the last was not readily available from the results of this study. However, statistical theory indicates (Wodtke, 1969) that if a non-significant difference among the test lists is once established, other factors (for example subject involvement or slight differences in level) must be the cause for different results.

There is almost nothing in the literature comparing speech perception for female and male speakers. Consequently, a series of tests were run to investigate this point. In this series of tests the MRT test material for one male and one female speaker was presented at the same speech level, as measured on the sound level meter, with three tests for each speaker. From an examination of the analysis of variance shown in Appendix C, it is concluded there is no significant difference in speech perception for male or female speakers, at least under the conditions of the material being presented at the same speech level. Whether there are differences under live circumstances where female speakers may use less vocal effort than male speakers was not investigated. While not shown in this analysis, some of the other tests also included both female and male speaker test lists, with no difference in test results.

TABLE II

SUMMARY OF ONE-WAY ANALYSIS OF VARIANCE TESTS

Case	Level	* P5%	Subjects /Tests	Other Remarks	Rm.
1.	66	Between subjects M.S. 326.36 $F = \frac{326.36}{10.79} = 31.1 <$ Between tests M.S. 11.386 $F = \frac{11.386}{10.79} = 1.05 >$ M.S. errors 10.79	10/6	with NC-45	312
2.	66	Between subjects M.S. 367.21 $F = \frac{367.21}{9.45} = 38.0 <$ Between tests M.S. 4.85 $F = \frac{4.85}{9.45} = 0.52 >$ M.S. errors 9.45	10/5	with NC-45 plus rotation	312
3.	62	Between subjects M.S. 18.75 $F = \frac{18.75}{5.3} = 3.55 <$ Between tests M.S. 47.6 $F = \frac{47.6}{5.3} = 9.0 <$ M.S. errors 5.3	9/5	AAC	312
4.	62	Between subjects M.S. 39.58 $F = \frac{39.58}{2.647} = 14.9 <$ Between test M.S. 1.867 $F = \frac{1.867}{2.647} = 0.71 >$ M.S. errors 2.647	6/5	GBC	312
5.	62	Between subjects M.S. 36.82 $F = \frac{36.82}{5.22} = 7.05 <$ Between tests M.S. 17.57 $F = \frac{17.57}{5.22} = 3.4 <$ M.S. errors 5.22	9/6	GBC	402
6.	62	Between subjects M.S. 74.71 $F = \frac{74.71}{2.05} = 36.1 <$ Between tests M.S. 37.41 $F = \frac{37.41}{2.05} = 18.7 <$ M.S. errors 2.05	9/6	AAC	402

*A 5% probability of chance will be taken to test the hypotheses, that there is no difference between the tests, and that there is no difference between the locations.

The next test was to determine whether subjects respond differently because of the location at which they are seated. This was investigated by "rotating" the listeners as mentioned previously. For completeness, a test was conducted in the usual manner followed by a ten minute break. Then the same test was repeated with subject rotation.

An analysis of variance similar to the one discussed above is given in Table II (Cases 1 and 2). The results (Appendix D. 2.) show that there is a significant difference among locations, while the test lists can be considered as being the same. This means that rotation of the subjects did not influence the results.

It can be assumed that test material is presented at different levels to listeners sitting at different locations (if two locations are compared). This assumption is later applied to find the correlation between SIL signal to noise ratio and the speech perception test scores.

This assumption is tested by the data in Room 312 after the ceiling change. In these cases two different speech levels were presented while all the other conditions were kept the same. In order to determine whether or not there was a significant difference due to this level change, another kind of analysis of variance was applied. The two-way analysis of variance with repeated measures on one factor considers the average score (for the listeners) obtained in the room due to the presentation level. In this case the effect can be either level or tests and the interaction between them. Table III summarizes this two-way analysis of variance.

Table III shows that the F ratio for the levels is larger than the critical five percent value. Therefore, the levels had a significant influence on the speech perception test score.

As mentioned previously, the differences among speech perception scores were not too large when only ambient noise was present (see Case 3 in Table II). The addition of noise increased the range of the scores for a given test, and thus heightened the influence of the location to give a better test of the influence of various signal to noise ratios on speech perception. The added noise was NC shaped to represent noises which might be present in classrooms - slide projector, unit ventilator, etc.

While no specific additional statistical analysis was done with these data (see Cases 1 and 2 in Table II), the data as given in Appendix C. 3. , and the contour maps 10, 11, 14, 15 and 16 show the influence of the added noise. Figure 10 shows the correlation between the SIL signal to noise ratio and the speech perception test score. The data used for this curve refer only to the middle sections of the tested rooms. Along the long middle axis of these rooms, the speech signal attenuation is predicted from the measured broad band noise

TABLE III

SUMMARY OF TWO-WAY ANALYSIS OF VARIANCE WITH REPEATED MEASURES ON ONE FACTOR

Number	Effect	S.S.	df	M.S.	F	P*	Remarks
1.	Level	187.2	1	187.2	8.0	<0.05	Speech level changes tested in Room 312, on 22/5, 9 subjects, 5 tests, original + Gypsum ceiling.
	Error	234.1	10	23.4			
	Tests	23.9	4	6.0	2.1	NS	
	Interaction	30.5	4	7.6	2.7	<0.05	
	Error	113.9	40	2.8			
2.	Ceiling	147.2	1	147.2	4.14	<0.05	Ceiling changes tested in Room 312, on 22/5 and 28/5, 6 subjects, 5 tests.
	Error	333.6	10	33.4			
	Tests	57.9	4	12.9	3.60	<0.05	
	Interaction	72.6	4	18.1	5.03	<0.05	
	Error	144.3	40	3.7			
3.	Ceiling	23.1	1	23.1	0.42	NS	Ceiling changes tested in Room 402, on 26/5 and 28/5, 9 subjects, 6 tests.
	Error	892.3	16	55.8			
	Tests	175.7	5	35.1	9.6	<0.05	
	Interaction	99.2	5	19.8	5.4	<0.05	
	Errors	291.0	80	3.6			

*A 5 percent probability of chance will be taken to test the different hypotheses.

attenuation, while the noise level was measured at each position. The scatter of the data is approximately ± 7 percent (speech perception test score) from the center line of the given curve, and the curve will be represented as a "strip" covering the scattered range. The plotted data points show relatively few data points were available for SIL signal to noise ratios between 0 and -10 dB. However, this range is not very important for this study as will be discussed later.

The data given in Table II and Table III and the contour maps 17, 18, 19 and 20 show the influence of the ceiling change on the speech perception test scores in Rooms 312 and 402. From these data it is rather difficult to determine whether or not there was a speech perception test score change due to ceiling change. Therefore, a two-way analysis of variance (similar to that used for testing the speech level influence) was carried out. The analysis of variance data, see Cases 2 and 3 in Table III, show, that for Room 312, under the given test conditions the obtained F ratio 4.41 approaches the critical five percent value (4.96). Therefore, the ceiling change in this room did influence the speech perception test scores, and that similar results might occur approximately six percent of the time because of chance alone. For Room 402, the F ratio is less than unity, which indicates that there was no significant score change due to the ceiling change. In other words, the change in the ceiling did not alter the room characteristics sufficiently to alter the test results.

CHAPTER IV

DISCUSSION

The Application of the Experimental Test Results for the Developed Classroom Design Guidelines

The development of the classroom design guidelines (described in the previous report) showed that experimental test results were needed in order to complete the design cycle. It was shown that, for a given number of students, a classroom could be designed, based on given design recommendations. The classroom's dimensions, as well as the absorption that has to be added in order to maintain a certain reverberation time in the room, could be determined easily. However, it was only possible to estimate the speech perception in the designed classroom by applying articulation index computation, described later in this section since certain assumptions had not been tested. The experimental test results, as explained earlier in this study, were to supply the information required about these assumptions. These experimental test results relate to the sound distribution in the tested spaces and to the speech perception in them. The end product of the first was given in Figure 6. These results, although obtained from broad band noise measurements, were used also for speech signal attenuation. The broad band noise measurements also showed that noise levels along the walls of the classroom could not be estimated by the same measure used for the estimation of noise attenuation along the long center axis of the room (for a speaker position as defined before). The measurements showed furthermore, that along the long center axis of the room the broad band noise attenuation measured in SIL dB, can be considered as an inverse function of the distance, depending at least partly, on the room constant R of the tested space.

The speech perception test scores obtained in this study depend obviously on the test conditions. Speech material presentation level, ambient noise level and acoustical room conditions are the main variables influencing the speech perception. But as the obtained data (test scores) for each test also included the noise level (measured data) at the time of testing, it was possible to compute the SIL signal to noise ratio related to the obtained score. The SIL signal to noise ratios and the speech perception test scores for each of the different tests provided the data for Figure 10, which gives the speech perception test score as a function of the SIL signal to noise ratio. This last function provides the correlation between the score and the noise conditions under which it was obtained. It makes possible the prediction of the speech perception for a given noise environment.

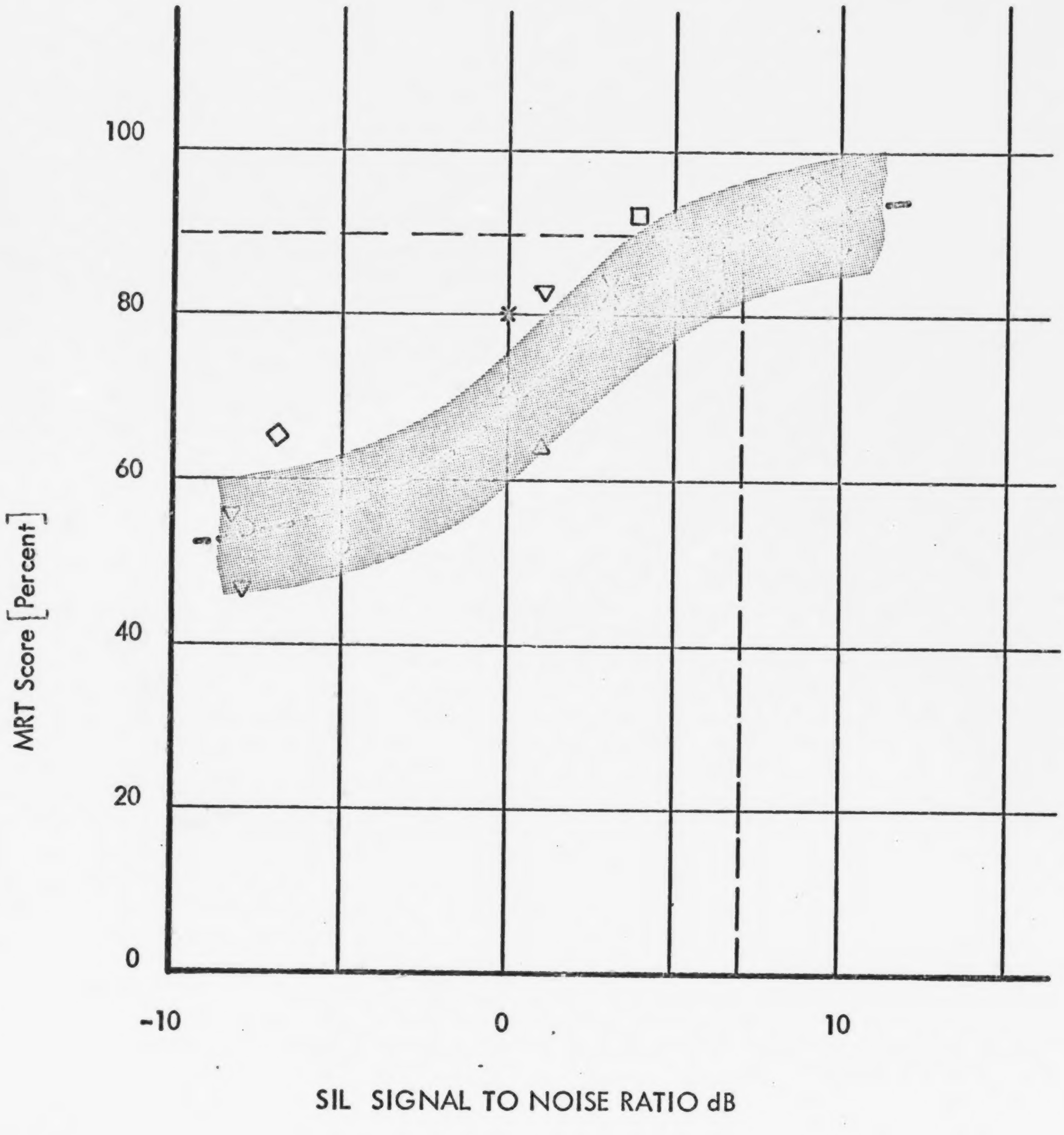


Figure 10. Speech Perception Test Results as a Function of SIL Signal to Noise Ratio

The final classroom design guidelines are shown in Figure 11. It consists of six figures and a "computational scale". Going from the upper right Figure 1 clockwise through the other figures will provide all the needed design data, as well as a check on the speech perception in the room. The classroom area evaluated by the last Figure 6 (speech perception test score as function of the SIL signal to noise ratio) is only along the long center axis of the room or approximately two-thirds of the classroom's area. However, if speech perception is good in this area, no difficulties are to be expected along the walls.

Figure 11. Rectangular Classroom Design Guidelines

The figure with its seven parts summarizes the classroom design guidelines, for designs applying the following assumptions:

a. Ratio of width to length - 2:3.

b. Height of classroom - 10 feet.

c. Floor area per student - 20 square feet.

d. Acoustic absorption of each student AA = 2.5 Sabins.

Note: The design guidelines were calculated for the above values, however, changes can be introduced.

The different parts of Figure 11 indicate the following:

1. Volume in cubic feet and optimum reverberation time in seconds, for different numbers of students (occupancy).

2. Absorption in sabins, for the octave band centered at 500 Hz, needed to maintain the optimum reverberation time. Total absorption A, considering the number of occupants S1.

3. Average absorption coefficient $\bar{\alpha}$, same for A and A1.

4. Room constant R in square feet, same for A and S1.

5. SIL signal attenuation over distance in dB,

   for R = 500 to 750 square feet, 3 dB attenuation per distance doubling,
   for R = 750 to 2000 square feet, 4 dB attenuation per distance doubling,
   for R = 2000 to 4500 square feet, 5 dB attenuation per distance doubling,
   and for free field 6 dB attenuation per distance doubling.

   Where the reference zero point is three feet from the speaker.

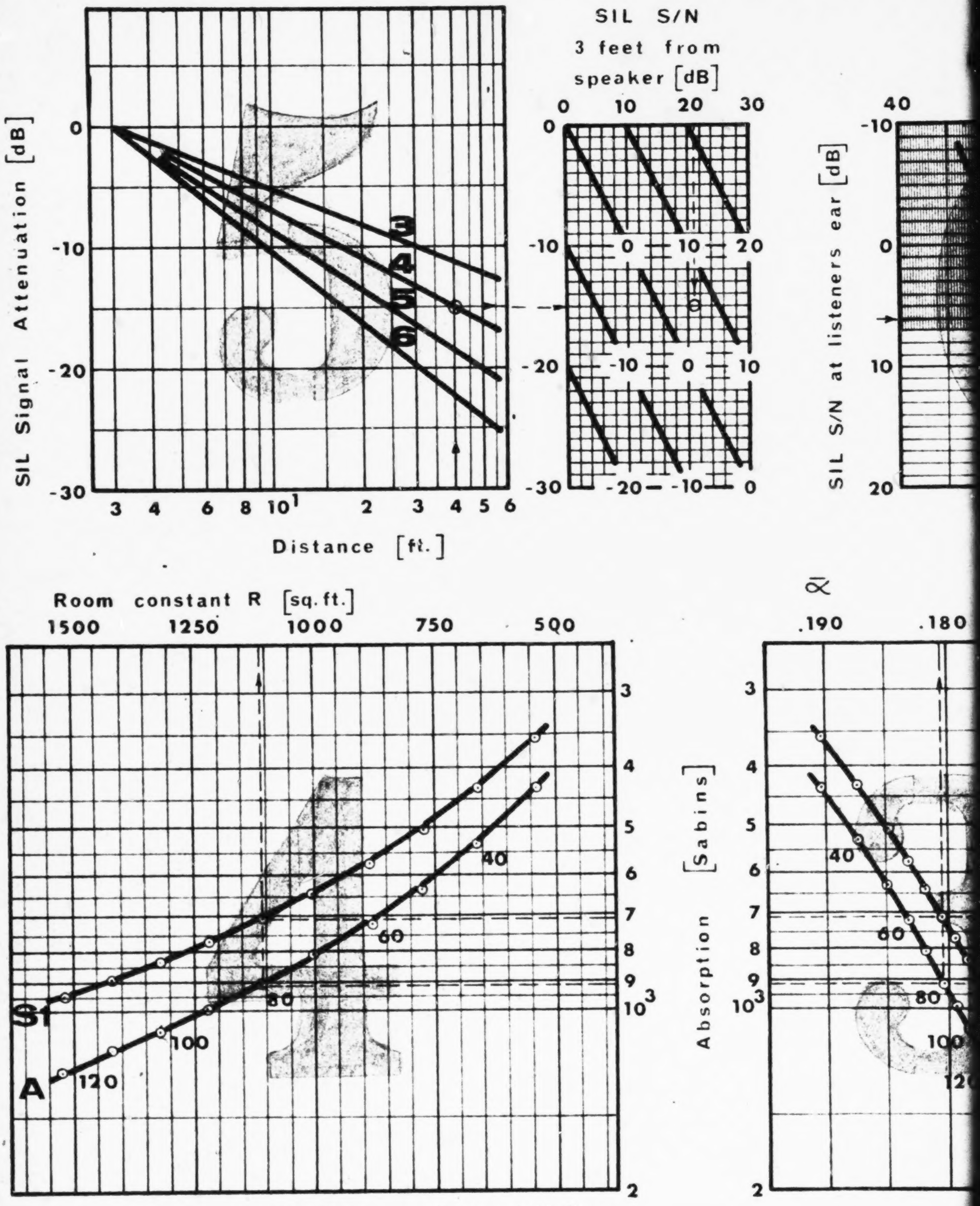
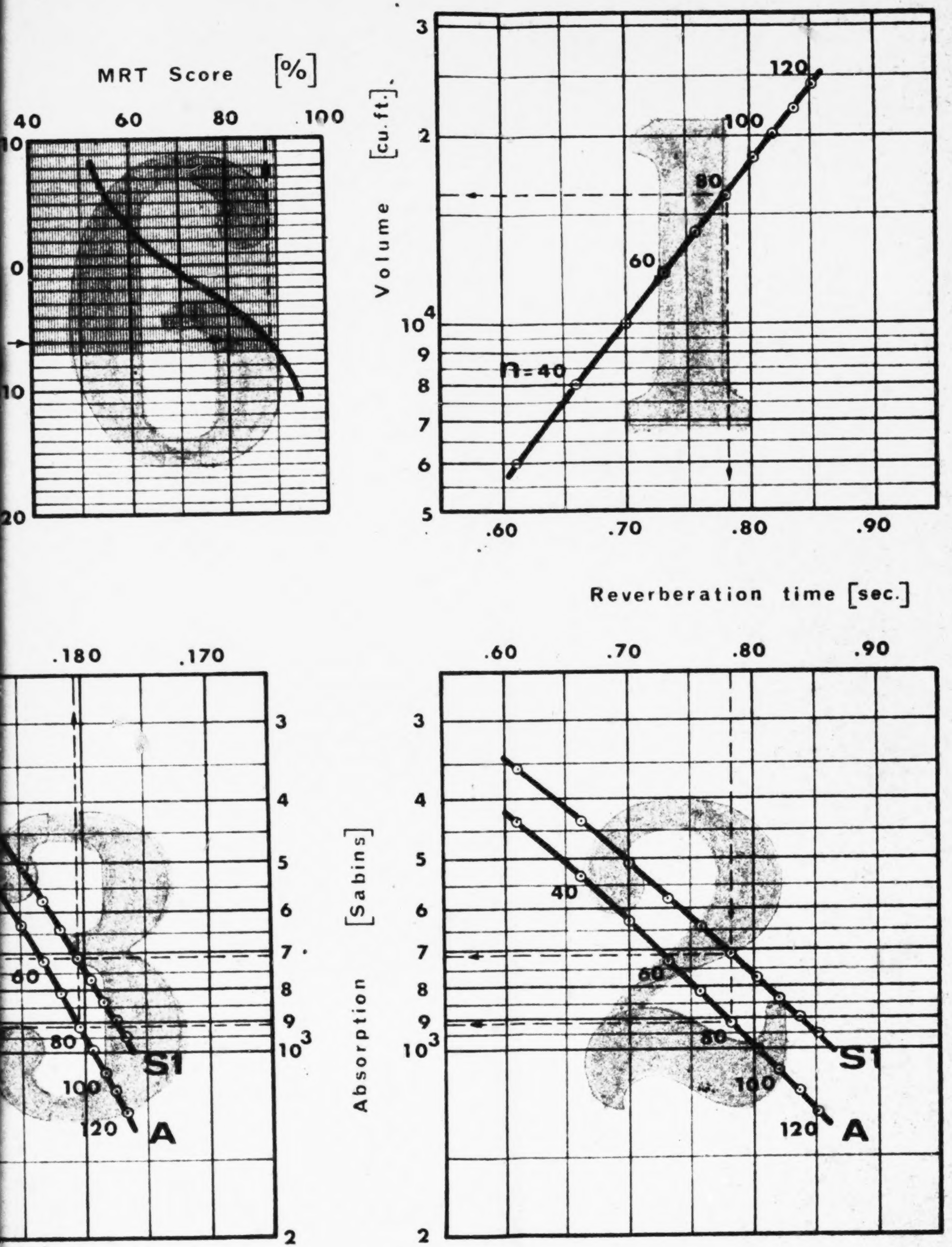


Figure 11. Rectangular Classroom Design Guidelines


MRT Score [%]
40
60
80
100
10
0
10
20
Volume [cu.ft.]
3
2
10^4
9
8
7
6
5
120
100
80
60
n=40
.60
.70
.80
.90
Reverberation time [sec.]
.180
.170
.60
.70
.80
.90
Absorption [Sabins]
3
4
5
6
7
8
9
10^3
2
40
60
80
100
120
S1
A

The computation scale is given in form of a small table to compute the SIL signal to noise ratio (S/N) at the listener's ear. The value is obtained by reading in the SIL S/N at three feet from the speaker, the SIL signal attenuation. The point at which the lines through those values meet, indicates the desired SIL value.

6. Estimated MRT score in percent as a function of the SIL S/N at the listener's ear. If the SIL S/N ratio is larger than 7 dB, the estimated MRT score will be higher than 90 percent, which is the minimum acceptable requirements.

Range of Application of the Design Guidelines

The range of application of these classroom design guidelines is limited by the range of expected student occupancy. The student range considered at present is from 30 to 120. For classrooms of larger size the basic design assumptions - ceiling height of 10 feet and floor area of 20 square feet per student will have to be changed.

Figure 11 also assumes an absorption (AA) of 2.5. This absorption is given as AA = 2.5 sabins per student, at 500 Hz, applying to high school or college students.

The reverberation times recommended for the given student number range and the corresponding volumes will allow good speech perception, other factors being favorable; classrooms will neither be too "live" nor too "dead", and, therefore, should be satisfactory both for the listener and the speaker.

Absorption should be placed in the room in order to maintain the optimum reverberation time. The ceiling is recommended for this purpose, with absorption starting after approximately the first third of the room length. It is advisable to spread the absorption material around the perimeter of the room, and if possible the absorption material should be applied in form of strips or squares. In this way the absorption material is used most efficiently, and the reflecting areas will permit better overall speech perception.

The design guidelines have a rather limited range of average absorption coefficient (29), $\bar{\alpha} = 0.190$ for the 30 student classroom, and 0.177 for the 120 student classroom. The room constants (R) are obviously influenced by the average absorption and their range is from 530 square feet (for 30 student classroom) to 1520 (for 120 student classroom). From the test, the above room constants should result in a signal attenuation of three to four SIL dB per doubling of distance. The difference between the usage of three or four dB attenuation per distance doubling will amount to approximately four dB (SIL) at the most distant listener's location in the large room; however, in small classrooms this influence will be much less significant.

The value of three dB (SIL) attenuation per distance doubling will be applied for R values that range from 500 to 750 square feet, and four dB (SIL) for R values ranging from 750 to 2000 square feet, when using the suggested guidelines. In cases where speech perception is evaluated in existing spaces, a specific "signal attenuation" will have to be chosen (see text to Figure 11), and the design guidelines could be used as a checking procedure.

The correlation between the speech perception test scores and the SIL signal to noise ratio which was obtained in the experimental study can be applied in the range given by the SIL signal to noise ratio. For other ranges it would be advisable first to obtain more experimental data.

Comparison with Other Studies

It is rather difficult to make a direct comparison with any other studies on speech perception, first, as those studies did not investigate speech perception testing in classroom type spaces, as was done in this study; and secondly, different measuring criteria were applied. However, the speech perception test data obtained in this study can be compared with end results given by Kryter (1966). In his report, speech perception scores for a 32 word vocabulary, sentences, rhyme tests, 256 phonetically balanced (PB) words, 1000 different PB words and 1000 nonsense syllables are compared. As the given curves summarize a large amount of data taken under different test conditions the author adds the following note. "These relations are approximate, they depend on the type of material and skill of talker and listeners." In the same study the speech perception scores are given as a function of the Articulation Index (AI). The articulation index is a somewhat complex computation (the method applied here is only one of the ways to compute AI), involving the octave band levels of the average voice in the five octaves centered at 250, 500, 1000, 2000 and 4000 Hz, weighted according to their contribution toward speech intelligibility. It takes into account the noise in the system, and the attenuation between speaker and listener. These are subtracted from the assumed voice levels.

Based on the above explanation, it is possible to compute the articulation index for any given speech signal to noise ratio (S/N) once the octave band analysis is given. The speech perception test data as a function of the signal to noise ratio obtained in this experimental study (using MRT), are recomputed and given as a function of the AI.

Speech perception test data obtained in this study are plotted in Figure 12, which also shows the approximate relations as given by Kryter. It can be seen in this figure, that although the obtained results are not the same (compared with Kryter's Rhyme Tests results) the obtained trend is the same.

Reference is often made to criteria for approximate listening conditions (Kingsbury and Taylor, 1968). From other studies it is possible to compare speech perception test scores obtained for different testing methods with sentence understanding. An articulation index of 0.5 is often found to be a minimum requirement for good sentence intelligibility. From the data obtained in this study, an MRT speech perception test score of 90 percent corresponds to an SIL signal to noise ratio of 7 dB. This corresponds to an AI value of approximately 0.6. From the data obtained in this study, Figure 12 shows that a 90 percent MRT score, for an AI of 0.6, corresponds to a 98 percent sentence understanding.

These values;
1) SIL signal to noise ratio 7 dB
2) MRT score 90 percent
3) Sentence understanding of 98 percent

will be taken as minimum requirements for acceptable speech perception in classrooms. These criteria will be applied in the numerical example following.

The requirement is to design a rectangular classroom for 80 students. Based on the design recommendations as given in Figure 11 the following can be read:

(1) Shows the volume V = 16,000 cubic feet, and the optimum reverberation time of T_{opt} = 0.78 seconds. From Figure 1, the floor area can be found, it is 1600 square feet, and the modul length is 16.5 feet. From Figure 2 the width and the length, 33 feet and 49.5 feet can be taken.

So far the room dimensions (W x L x H) 33 feet x 49.5 feet x 10 feet and the optimum reverberation time 0.78 second are given.

(2) Shows the absorption needed to maintain the optimum reverberation time. The total absorption needed is, A = 910 Sabins, while the absorption needed in addition to the 80 students is, S1 = 710 Sabins.

(3) Shows the average absorption coefficient, $\bar{\alpha}$ = 0.181.

(4) Shows the room constant R of the designed room, R = 1110 square feet. Along the long axis of the room (R = 1000 square feet), a speech signal attenuation of four SIL dB per doubling of distance can be assumed.

(5) Shows that an attenuation 15 SIL dB is expected at 40 feet from the speaker (if the speaker stands approximately three to six feet from the wall, and the reference point is three feet from the speaker).

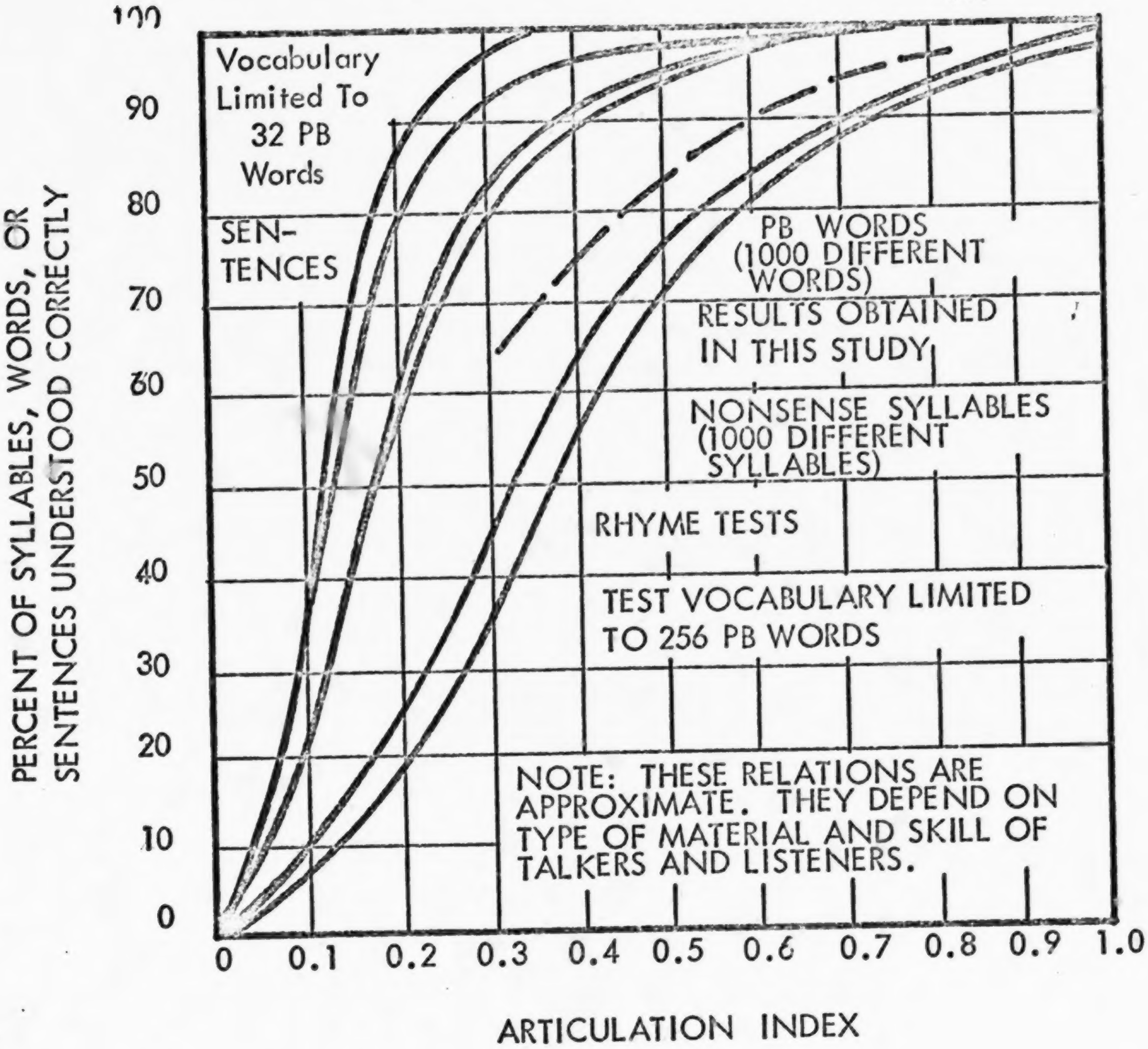


Figure 12. Relationship Between Articulation Index and Speech Intelligibility (20)

With this information, it is possible to check speech perception.

The following basic assumptions are made:

a. "Normal" speech level is applied (66 dB overall, or 56 dB SIL).

b. Background noise level (noise with people present) in the room will be NC-35. This level can be considered as normal to low.

From the above speech and noise data, the SIL signal to noise ratio at three feet from the speaker is computed, it will be 21 dB (56 - 35). Checking the computation scale for SIL signal to noise ratio 21 dB (at three feet from the speaker), and an attenuation of 15 dB, shows that the SIL signal to noise ratio at the most distant listener's location is 6 dB (21 - 15).

(6) Shows that in case of SIL signal to noise ratio of 6 dB, an MRT speech perception test score of approximately 88 percent can be expected.

Therefore, it might be concluded that this classroom meets the minimum requirements under the above circumstances. However, if the background noise is higher, say NC-40, the score in case of normal speech level will only be 72 percent (which is much too low). In order to obtain acceptable speech perception (although not always the most recommended way) the speakers' level will have to be raised. "Raised" voice (72 dB overall, or 62 dB SIL) will provide the acceptable speech perception score (90 percent).

Another way of summarizing the data obtained is shown in Table IV. In actuality, this table extends the data usually shown for maximum SIL values for face to face communication in free space to enclosed spaces typical of classrooms and for different and higher values of expected AI. In both cases, no visual cues are included.

The design implications of this table are quite clear. A common classroom noise level with currently used heating and ventilating equipment is NC-40, and the expected attenuation with distance is at least 4 dB with the usual full ceiling acoustical absorption. Under these conditions, it is difficult to maintain acceptable speech intelligibility at frequently encountered classroom distances, without the teacher raising his or her voice above the "raised voice" level. It is also obvious that a significant contribution to intelligibility can be obtained by lowering the obtained classroom ambient noise level to NC-35 and controlled amounts of absorption.

TABLE IV

PREDICTED SPEECH INTELLIGIBILITY IN NOISE

Speech Level	Ambient or Background Noise															Attenuation per Distance Doubling
	NC-25			NC-30			NC-35			NC-40			NC-45			
Desired AI	.5	.6	.7	.5	.6	.7	.5	.6	.7	.5	.6	.7	.5	.6	.7	
"Normal" 66 dB overall, 56 dB SIL	-	-	-	-	-	-	-	70	37	45	25	12	-	-	-	3
	-	-	-	-	-	47	55	33	20	24	14	8	-	-	-	4
	-	-	60	60	42	28	32	21	14	16	10	7	-	-	-	5
"Raised Voice" 72 dB overall, 62 dB SIL	-	-	-	-	-	-	-	-	-	-	-	45	60	30	15	3
	-	-	-	-	-	-	-	-	55	62	40	24	28	17	10	4
	-	-	-	-	70	50	70	50	32	37	25	16	18	12	8	5

Distance in feet from the speaker at which the speech intelligibility, as indicated by the AI, will be at or above the indicated value.

Suggestions for Future Research

We need to know more about the live perception of speech in classrooms. The following are offered as suggestions for additional research in this area.

1) Additional tests with more observers to further validate and, hopefully, narrow the limits on the relation between signal to noise ratio and MRT scores, as shown in Figure 10.

2) Additional work to determine the actual levels, and differences in levels, of voice presentation by male and female teachers under differing classroom conditions.

3) Speech perception and acoustical studies in other than rectangular classrooms, extending to current open-plan classroom designs.

APPENDIX A

ROOM CHARACTERISTICS TEST RESULTS

The appendix includes data on the following:

1. Reverberation Time, Averaged Test Results
2. Ambient Noise Data
3. Ambient Noise + NC Shaped Noise Data
4. Broad Band Noise Distribution (Signal Attenuation), Data

NOTE: All location coordinates are given in feet starting from upper left corner of concerned classroom, when standing with back toward the blackboard. (see Figure 5)

A. 1. Reverberation Time, Averaged Test Results

Reverberation time was measured in the three rooms as explained. The data given here are an average computed from ten decay curves.

Reverberation Times Before Ceiling Change

Frequency Hz	Rooms 209	312	402
125	0.51	0.75	0.59
250	0.43	0.59	0.46
500	0.37	0.51	0.39
1000	0.46	0.58	0.53
2000	0.46	0.58	0.77
4000	0.43	0.59	0.70

Reverberation Time After Ceiling Change

Frequency Hz	Rooms 209	312	402
125	-	0.84	0.40
250	-	0.62	0.56
500	-	0.63	0.47
1000	-	0.64	0.60
2000	-	0.78	0.74
4000	-	0.76	0.91

A. 2. Ambient Noise Data

The data are given in SIL dB. The same values were later used as input data for computer contour mapping.

Location Y	X	SIL (dB)
27.	3.	37.
21.	3.	35.
15.	3.	33.
9.	3.	34.
3.	3.	32.
27.	10.5	34.
21.	10.5	34.
15.	10.5	34.
9.	10.5	34.
3.	10.5	34.
27.	18.	35.
21.	18.	35.
15.	18.	34.
9.	18.	34.
3.	18.	35.

Ambient Noise Distribution Data,
209 Keller, Acoustic Ceiling

Location Y	X	SIL (dB)
51.	3.	33.
39.	3.	32.
30.	3.	32.
21.	3.	33.
12.	3.	34.
3.	3.	36.
51.	16.5	32.
39.	16.5	34.
30.	16.5	34.
21.	16.5	33.
12.	16.5	33.
3.	16.5	34.
50.	30.	35.
39.	30.	35.
30.	30.	36.
21.	30.	33.
12.	30.	34.
3.	30.	35.

Ambient Noise Distribution Data,
312 Keller, Acoustic Ceiling

Location Y	X	SIL (dB)
48.	3.	31.
39.	3.	30.
30.	3.	30.
21.	3.	31.
12.	3.	32.
3.	3.	32.
48.	16.5	34.
39.	16.5	32.
30.	16.5	32.
21.	16.5	32.
12.	16.5	31.
3.	16.5	31.
48.	30.	34.
39.	30.	33.
30.	30.	33.
21.	30.	31.
12.	30.	36.
3.	30.	33.

Ambient Noise Distribution Data,
402 Keller, Acoustic Ceiling

A.3. Ambient Noise + NC Shaped Noise Data

The data are given in SIL dB. The same data values were later used as input data for computer contour mapping.

Location Y	X	SIL (dB)
27.	3.	42.
21.	3.	42.
15.	3.	43.
9.	3.	44.
3.	3.	45.
21.	10.5	42.
9.	10.5	50.
3.	10.5	48.
27.	18.	41.
21.	18.	42.
15.	18.	43.
9.	18.	45.
3.	18.	45.

Ambient Noise + NC-50 Distribution
Data, 209 Keller, Acoustic Ceiling

Location Y	X	SIL (dB)
39.	3.	33.
21.	3.	37.
3.	3.	40.
39.	16.5	34.
12.	16.5	46.
3.	16.5	41.
39.	30.	35.
30.	30.	37.
21.	30.	38.
3.	30.	38.

Ambient Noise + NC-45 Distribution Data, 312 Keller, Acoustic Ceiling

Location Y	X	SIL (dB)
48.	3.	33.
39.	3.	33.
21.	3.	38.
12.	3.	40.
3.	3.	41.
39.	16.5	34.
21.	16.5	39.
12.	16.5	46.
3.	16.5	47.
48.	30.	35.
39.	30.	35.
21.	30.	41.
3.	30.	41.

Ambient Noise + NC-45 Distribution Data, 402 Keller, Acoustic Ceiling

A. 4. Broad Band Noise Distribution Data

The data are given in SIL dB. The same values were used later as input for computer contour mapping.

Location Y	X	SIL (dB)
27.	3.	62.
21.	3.	63.
15.	3.	63.
9.	3.	62.
3.	3.	62.
27.	10.5	75.
21.	10.5	69.
15.	10.5	65.
9.	10.5	62.
3.	10.5	62.
27.	18.	62.
21.	18.	63.
15.	18.	64.
9.	18.	61.
3.	18.	62.

Broad Band Noise Distribution Data,
209 Keller, Acoustic Ceiling

Location Y	X	SIL (dB)
51.	3.	63.
39.	3.	62.
30.	3.	61.
21.	3.	60.
12.	3.	59.
3.	3.	58.
51.	16.5	75.
39.	16.5	67.
30.	16.5	64.
21.	16.5	62.
12.	16.5	61.
3.	16.5	60.
50.	30.	64.
39.	30.	63.
30.	30.	61.
21.	30.	61.
12.	30.	59.
3.	30.	58.

Broad Band Noise Distribution Data,
312 Keller, Acoustic Ceiling

Location Y	X	SIL (dB)
48.	3.	65.
39.	3.	63.
30.	3.	63.
21.	3.	61.
12.	3.	60.
3.	3.	60.
48.	16.5	75.
39.	16.5	68.
30.	16.5	64.
21.	16.5	62.
12.	16.5	61.
3.	16.5	60.
48.	30.	65.
39.	30.	64.
30.	30.	62.
21.	30.	60.
12.	30.	60.
3.	30.	60.

Broad Band Noise Distribution Data,
402 Keller, Acoustic Ceiling

APPENDIX B

SPEECH PERCEPTION TEST MATERIAL

This appendix contains the three forms (each of which consists of six test lists) of speech material to be read by the speaker for the Modified Rhyme Test. It also contains an instruction form used in this study for training purposes only. Another instruction sheet gives instructions for the use of the answer sheets. As every test list contains 50 words, the statistical analysis uses an error count based on 50 items. On the other hand, the contour maps will apply speech perception test scores, or the percent correct.

MODIFIED RHYME TEST

Name____________________ Position____________________

Room____________________ Condition____________________

Comments:

I. INSTRUCTIONS:

Your attention, please. This is a test to see how well you can hear words in quiet and in a background of noise. First, here are some practice words. On your answer sheet, underneath the heading "PRACTICE," are five groups (to be called "blocks") of words, six words in each group or block. I will say one of the words in practice block number 1; you are to decide which word it was, and then draw a line through that word. Then I will say a word in practice block number 2, and you will draw a line through the word in that block, and so on. Now here are the practice samples.

II. PRACTICE:

1.
swell sell
yell tell
smell well

2.
mole moan
most mold
mode more

3.
grim slim
him rim
dim whim

4.
bets bell
bet belt
beg bend

5.
link mink
think wink
drink shrink

III. TEST:

Now get ready for the test. The test is divided into parts; each part contains 50 words. The announcer will say the number of the block, and then say the test word. Just as you did in practice, listen carefully, decide which word in the block was spoken, and draw a heavy line through it; be sure to do this in each block, even if you are not always certain what the word was. Here is the test. Remember, please guess when necessary.

The practice items for the two remaining test forms are:

FORM 2

1.
nine mine
line pine
wine fine

2.
mix mist
miss milk
mill mint

3.
star par
tar far
car char

4.
stitch stick
still stiff
stilt sting

5.
wink wish
wind wing
with witch

FORM 3

1.
job rob
mob knob
throb bob

2.
luck lump
lung lug
lunch lust

3.
dam ram
slam clam
jam ham

4.
hid hint
him hiss
hinge hitch

5.
mile mite
mine mice
mike mind

MODIFIED RHYME FORM 1

Name_________________________ Position_________________________

Room_________________________ Condition_________________________

1. sing sit sin sill sip sick	2. look shook cook took hook book	3. vest rest next test best west	4. kill kid kit king kith kiss	5. putt puff pub pun pup pug
6. fin fig fit fib fill fizz	7. toil boil foil soil coil oil	8. rust must just gust dust bust	9. rig pig wig big jig fig	10. sane save safe same sale sake
11. bit hit sit wit fit kit	12. came cape cane cake cave case	13. hold cold fold gold told sold	14. mass map math man mad mat	15. sale pale gale bale male tale
16. raw saw paw thaw jaw law	17. rent went dent sent tent bent	18. pace pale page pay pave pane	19. came game name fame same tame	20. dub dull dun duck dud dug
21. rake rave ray raze rate race	22. bill hill fill will kill till	23. pan pang pad pass pat path	24. keel peel reel eel feel heel	25. bus bun buff buck bug but
26. heath heat heave hear heal heap	27. sag sack sat sass sap sad	28. gun nun run sun bun fun	29. tick pick sick wick lick kick	30. cuff cup cud cub cuss cut
31. peace peak peach peat peal peas	32. pay way gay may say day	33. den pen hen men ten then	34. seat beat meat heat feat neat	35. dip hip rip sip lip tip
36. dip din dim did dig dill	37. team teak tease tear teach teal	38. sub sun sung sup sud sum	39. pig pill pin pick pip pit	40. fed red shed wed bed led
41. mop shop top hop cop pop	42. lane lame lace lay lake late	43. beach beat bean beak bead beam	44. sang hang gang bang rang fang	45. seep seed seem seethe seen seek
46. park dark mark bark lark hark	47. pin din sin tin fin win	48. tab tang tan tam tack tap	49. bath back bat ban bass bad	50. hot not tot got lot pot

MODIFIED RHYME FORM 2

Name________________________ Position________________________

Room________________________ Condition________________________

1. mop top hop shop cop pop	2. din sin fin pin win tin	3. back bath bass ban bad bat	4. tot lot hot got pot not	5. cut cuff cud cub cuss cup
6. peas peace peach peal peak peat	7. jig big rig pig wig fig	8. safe same save sane sale sake	9. name same game fame came tame	10. dun dud dub dug duck dull
11. sup sud sun sung sub sum	12. tam tang tap tab tan tack	13. law saw raw paw jaw thaw	14. pill pip pin pick pit pig	15. ten hen den pen then men
16. sick pick lick tick wick kick	17. coil oil toil foil soil boil	18. bust dust rust must gust just	19. fold hold cold sold gold told	20. mad mass mat map math man
21. say gay pay way may day	22. shook look book took cook hook	23. fit fill fig fizz fib fin	24. tent sent bent went dent rent	25. pass pat pad pang path pan
26. beat beak beam bean beach head	27. neat heat beat meat feat seat	28. cave cape came cane case cake	29. seed seethe seek seep seen seem	30. dark hark bark park mark lark
31. feel peel heel eel keel reel	32. pale tale gale male bale sale	33. fang gang bang sang hang rang	34. rave rate raze race ray rake	35. bill will kill hill till fill
36. pane pay pale pave page pace	37. team teak tear teel tease teach	38. red led fed wed bed shed	39. heat heave heath heal hear heap	40. sag sap sass sat sad sack
41. fun nun gun run sun bun	42. pun pup puff putt pub pug	43. lane lace lame late lake lay	44. tip lip sip dip rip hip	45. dill dig din dip dim did
46. vest best test rest nest west	47. fit wit kit sit bit hit	48. kid king kill kit kiss kith	49. sit sin sip sing sill sick	50. but bug bus bun buff buck

MODIFIED RHYME FORM 3

Name____________________ Position____________________

Room____________________ Condition____________________

1. fang bang rang hang gang sang	2. mark bark park hark lark dark	3. peel keel feel eel reel heel	4. tang tab tam tap tack tan	5. sick sit sing sin sill sip
6. mass map mad man mat math	7. pup pug putt puff pun pub	8. hop pop top cop shop mop	9. best west nest rest test vest	10. cuff cup cud cut cub cuss
11. sale sake safe save sane same	12. dust rust just gust bust must	13. heave heal heath heap hear heat	14. dim din did dig dip dill	15. took look cook hook book shook
16. sap sat sag sass sack sad	17. gun run bun nun sun fun	18. page pale pane pay pave pace	19. got hot tot pot lot not	20. tick wick pick sick kick lick
21. wit fit sit hit bit kit	22. kith kit kiss kid king kill	23. foil oil coil toil soil boil	24. fig rig pig wig big jig	25. peach peas peal peak peat peace
26. pill pip pig pin pit pick	27. sup sung sun sum sud sub	28. fizz fit fill fib fig fin	29. bent tent went dent sent rent	30. pat pang pass pan pad path
31. teach tear teak team teal tease	32. dud dun dub dull dug duck	33. beak beam beat bead beach bean	34. way say may day gay pay	35. then hen pen men ten den
36. paw saw thaw law jaw raw	37. lane lace lake lay lame late	38. pale tale bale gale male sale	39. till bill fill kill hill will	40. bed wed fed led red shed
41. hold gold fold cold sold told	42. bun buff bug buck but bus	43. seed seem seep seen seethe seek	44. sin tin win din fin pin	45. neat heat beat meat seat feat
46. fame name came same game tame	47. sip rip hip tip lip dip	48. bath back ban bad bass bat	49. cake cape case cane cave came	50. race rate rake ray raze rave

APPENDIX C

STATISTICAL ANALYSIS

The statistical analysis carried out in this study was essential in order to evaluate the speech perception test results obtained under the different conditions in the tested spaces. As such the statistical analysis was concerned with the following:

1. The Frequency Distribution of the Speech Perception Test Results
2. Correlation Between the Different Test Lists
3. Analysis of Variance Tests

   The Appendix applying the analysis of variance will not comprise detailed statistical developments, nor will it develop most of the equations used. Those can be found in the referenced text books*. However, for one case a complete computational example will be given. The analysis applies computer library programs, written in FORTRAN IV, which are used on the IBM 360-67 computer at The Pennsylvania State University. As those programs were used merely as a computational assisting took they will not be given in detail. However, reference will be made to the specific name of the library program.

C. 1. The Frequency Distribution of the Speech Perception Test Results

The Central Limit Theorem for Sample Means is often applied when the analyzed data consists of results that involve subjective evaluation. It follows from this theorem that a distribution of sample means computed from random samples will form a normal distribution (assuming that the random samples yielding the means are large enough). Based on this theorem, data obtained from tests that involve subjective evaluation can be considered as having a normal distribution. In case of frequency distribution of speech articulation test scores, it was found that they tend to be normally distributed around the mean.

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*Winer, B. J. Statistical Principles in Experimental Design. McGraw-Hill, New York, 1962.
Weinberg, G. H. et al. Statistics: An Intuitive Approach, Books/Cole Publishing Co., Los Angeles, 1969.

In this study, a normal distribution of a listener's scores at a particular location was assumed, based on the above. However, the frequency distribution of the speech perception test results for a whole group (22 listeners) taking three similar tests in Room 209, under the same conditions was drawn. Figure 13 shows the frequency distribution. It can be seen that the distribution clusters around the mean, and that it tends to form a normal distribution.

C. 2. Correlation Between the Different Test Lists

Correlation may be defined as a relationship between different variables. Two variables may have a direct or positive correlation, no correlation, or a negative correlation. In case of a positive correlation the increase of one variable by a given amount will always imply a specified increase in the other variable. For the case of no correlation, as one variable changes, the other shows absolutely no overall trend to change in a uniform way with respect to it. For the case of negative correlation, as one variable increases, the other tends to decrease correspondingly in a uniform way.

The correlation may be constructed as a relation between two sets of Z scores (ratio distance score divided by standard deviation.) A simpler correlation computation will be used here. It is the one often called 'Pearson Product Moment Correlation Coefficient.' It is symbolized by the letter r. It is indicative of both the direction and the strength of the correlation. Analytically it can be defined as "The mean of the cross products of the Z scores of two variables." It is given by the following equation:

$$r = \frac{N\sum XY - (\sum X)(\sum Y)}{\sqrt{N\sum X^2 - (\sum X)^2} \cdot \sqrt{N\sum Y^2 - (\sum Y)^2}}$$

where:

X - the distribution of the first variable

Y - the distribution of the second variable

XY - the cross product of the two

In our case the number of variables was more than two, and therefore, a library computer program PPMCC (Pearson Product Moment Correlation Coefficient) was used.

The correlation computation establishes the correlation between the different test lists. By looking at the results as given in Table V, it can be seen that a positive correlation was obtained for all cases, except for one. It can be seen that the correlation was not always equally high. However, increased positive correlation can be seen after the ceiling change was introduced, and with the adding of additional noise.

TABLE V

SUMMARY OF CORRELATION TESTS

No.	Level	Test List Number (TLN)					T. L. N.	Means per Test	S. D. per Test	Subjects /Tests	Other Remarks
	dB	1	2	3	4	5					
								37.9	8.157		
1.	66	0.87					2	37.0	9.955	10/6	Ambient
		0.83	0.86				3	39.2	7.871		+ NC-45
		0.97	0.82	0.84			4	37.0	7.424		312
		0.96	0.81	0.79	0.95		5	38.4	6.346		5/19
		0.84	0.89	0.79	0.74	0.76	6	36.3	7.573		AAC
								38.3	6.634		Rotation
2.	66	0.87					2	38.4	7.427	10/5	Ambient + NC-45
		0.87	0.95				3	39.0	8.563		312
		0.84	0.95	0.98			4	37.5	10.550		5/19
		0.94	0.94	0.94	0.92		5	37.3	11.010		AAC
								36.3	3.722		
3.	62	0.25					2	38.2	2.333	9/5	Ambient
		0.34	0.16				3	38.9	2.713		312
		0.75	0.61	0.49			4	42.2	2.163		5/28
		0.58	-0.34	0.38	0.25		5	40.9	3.586		AAC
								42.7	2.503		
4.	62	0.87					2	42.7	2.582	6/5	Ambient
		0.76	0.50				3	42.3	3.327		312
		0.66	0.59	0.91			4	42.5	4.087		5/22
		0.97	0.82	0.85	0.75		5	41.3	3.077		GBC

TABLE V (cont'd)

SUMMARY OF CORRELATION TESTS

No.	Level dB	Test List Number (TLN) 1	2	3	4	5	T. L. N.	Means per Test	S.D. per Test	Subjects /Tests	Other Remarks
								40.4	4.157		
5.	62	0.94					2	42.7	4.183	9/6	Ambient
		0.88	0.93				3	44.2	4.116		402
		0.89	0.90	0.75			4	40.7	3.082		5/26
		0.81	0.89	0.76	0.79		5	45.3	3.082		AAC
		0.92	0.94	0.88	0.95	0.76	6	41.0	3.775		
								43.3	2.693		
6.	62	0.68					2	40.9	4.256	9/6	Ambient
		0.83	0.37				3	42.7	2.449		402
		0.68	0.87	0.31			4	39.8	4.014		5/28
		0.45	0.42	0.36	0.44		5	41.9	2.934		GBC
		0.56	0.47	0.26	0.41	0.62	6	40.1	2.619		

The table summarizes the correlation tests for the different test order combinations. In addition, it gives the means per test, as well as the standard deviation per test. The number of listeners and the number of tests (lists) conducted are given in addition to details on speech level, date of testing, room, background noise and ceiling condition.

These changes in correlation and even the single negative correlation obtained, are not surprising taking in account the number of variables involved in the speech perception testing as carried out in this study.

C. 3. Analysis of Variance Tests

Analysis of variance with repeated measures is often used in the behavioral sciences. In this study two kinds of analysis of variance were discussed; one-way analysis of variance and the two-way analysis of variance, both with repeated measures.

A numerical example of a one-way analysis of variance is given, in order to avoid lengthy explanations. For more detailed information the reference should be consulted.

Numerical example:

Six subjects participated in the test, and five test lists were presented to the subjects. The range of the sum Σ Tk (between subjects) is from 192 to 236, while the range of the sum ΣXn (between tests) is from 248 to 256. From this data alone it can be seen that the variation due to location is larger than due to different list presentation. Furthermore, the computation is carried out for the "between subjects" and for the "tests" using given equations. Finally the residual term (error term) is found. Knowing the sum of the squares and the degrees of freedom, the mean square is found. The F ratios are then computed and checked against the critical value given in the F ratio table. In our case for the difference between subjects $F_{0.95}(5,20) = 2.71$ and for the difference between tests $F_{0.95}(4,20) = 2.87$. Table VI gives the details of the above rather briefly carried out computational example.

C. 4. Analysis of Variance with Nested Factor Design

In that part of the investigation that tested the differences between male and female speaker, an analysis of variance with nested factor design was used. It was necessary to use this design as different test lists were used by the two speakers.

The example shows the computation without this time going into deeper explanations.

The data X_{in}, X_{in}^2, $\sum_{n=1}^{11} X_{in}$, $\sum_{n=1}^{11} X_{in}^2$, $(\sum_{n=1}^{11} X_{in})^2/n$ and $\sum_{n=1}^{11} X_{in}^2 - ({}_{n=1} X_{in})^2/n$ are given in Table VII, while the computation showing the used equations follows.

TABLE VI

ONE-WAY ANALYSIS OF VARIANCE NUMERICAL EXAMPLE

Subject	Test List 1		Test List 2		Test List 3		Test List 4		Test List 5		Total (T_K)	
											ΣT_K	$(\Sigma T_K)^2$
1	44	1936	43	1849	42	1764	40	1600	42	1764	211	44251
2	40	1600	41	1681	37	1369	36	1296	38	1444	192	36864
3	47	2209	47	2209	47	2209	48	2304	47	2209	236	55696
4	41	1681	40	1600	44	1936	44	1936	40	1600	209	43681
5	42	1764	44	1936	41	1681	44	1936	40	1600	211	44521
6	42	1764	41	1681	43	1849	43	1849	41	1681	210	44100
											$\frac{\Sigma(\Sigma T_K)^2}{K} = \frac{269383}{5} = 53876.5$	
ΣX_n	256		256		254		255		248		$\Sigma\Sigma X = 1269 = G$	
$(\Sigma X_n)^2$	65536		65536		64516		65025		61504		$\Sigma(\Sigma X_n^2) = \frac{322117}{6} = 53686.1$	
ΣX_n^2		10954		10956		10808		10921		10298	$\Sigma\Sigma X^2 = 53937$	

$$\text{SS between subjects} = \frac{\Sigma(\Sigma T_K)^2}{K} - \frac{G^2}{K.n} = 53876.5 = 43678.7 = 197.8 \quad F = \frac{\text{MS subjects}}{\text{MS res.}} = \frac{39.6}{2.66} = 14.8$$

$$\text{SS tests} = \frac{\Sigma(\Sigma X_n)^2}{n} - \frac{G^2}{K.n} = 53686.1 - 53678.7 = 7.4 \quad F = \frac{\text{MS tests}}{\text{MS res.}} = \frac{1.85}{2.66} = 0.70$$

$$\text{SS residual} = \Sigma\Sigma X_n^2 - \frac{\Sigma(\Sigma X_n)^2}{n} - \frac{\Sigma(\Sigma T_K)^2}{K} + \frac{G^2}{n.K} = 53.1$$

	SS	df	M.S.	F	P
Bet. Subjects	197.8	5	39.6	14.8	< 0.05
Within Tests	7.4	4	1.85	0.70	> 0.05
Residual	53.1	20	2.66		

TABLE VII

TABLE FOR EXAMPLE OF ANALYSIS OF VARIANCE OF NESTED FACTOR DESIGN

		MAN						WOMAN					
Location	(n)/(i)	X_1	X_1^2	X_2	X_2^2	X_3	X_3^2	X_4	X_4^2	X_5	X_5^2	X_6	X_6^2
3	1	40	1600	42	1764	42	1764	44	1936	45	2025	45	2025
4	2	39	1521	29	841	37	1369	37	1369	36	1296	46	2116
5	3	29	841	33	1089	26	676	27	729	34	1156	30	900
6	4	34	1156	33	1089	36	1296	31	961	36	1296	41	1681
9	5	43	1849	45	2025	43	1849	47	2209	44	1936	46	2116
10	6	36	1296	32	1024	36	1296	40	1600	38	1444	39	1521
11	7	33	1089	33	1089	39	1521	42	1764	35	1225	36	1296
12	8	34	1156	25	625	38	1444	34	1156	35	1225	36	1296
16	9	36	1296	34	1156	36	1296	42	1764	27	729	37	1369
17	10	30	900	36	1296	31	961	36	1296	27	729	35	1225
18	11	37	1369	38	1444	41	1681	42	1764	38	1444	42	1764
$\sum_{n=1}^{11} X_{in}, \sum_{n=1}^{11} X_{in}^2$		422	14073	380	13442	405	15152	422	16548	395	14505	433	17309
$(\sum_{n=1}^{11} X_{in})^2/n$		13898		13127		14911		16189		14184		17044	
$\sum_{n=1}^{11} X_{in}^2 - (\sum_{n=1}^{11} X_{in})^2$			175	315		241		359		321		265	

$$\text{SS between speaker} = \frac{\text{Tman}^2 + \text{Twoman}^2}{\text{n x i}} - \frac{G^2}{2(\text{n x i})}$$

$$= \frac{1176^2 + 1250^2}{33} - \frac{(2426)^2}{66}$$

$$= 51.7$$

$$\text{MS} = \frac{\text{SS}}{\text{df}}$$

$$\text{MS between speaker} = \frac{51.7}{(2-1)} = 51.7$$

SS within tests = SS within tests man + SS within test woman

$$\text{SS within test man} = \frac{\sum_{i=1}^{3} \sum_{n=1}^{11} X_{in}^2}{n} - \frac{(G_{man})^2}{\text{n x i}}$$

$$\text{SS within test woman} = \frac{\sum_{i=4}^{6} \sum_{n=1}^{11} X_{in}^2}{n} - \frac{(G_{woman})^2}{\text{n x i}}$$

$$\text{SS within tests} = \frac{\text{SS within tests}}{(i-1)(i-1)} = \frac{98.1}{4} = 24.5$$

Residual:

$$\text{Test (i)} \sum_{n-1}^{11} X_n^2 - \frac{(\sum X_n)^2}{N} = \text{SS within test}$$

$$\text{SS res.} = \sum_{i=1}^{6} \left(\sum_{n=1}^{11} X_{in}^2 - \left(\sum_{n=1}^{11} X_{in} \right) \right)$$

$$\text{MS} = \frac{\text{SS res.}}{\text{df}}$$

$$\text{MS} = \frac{175 + 315 + 241 + 359 + 321 + 265}{60} = 27.9$$

$$\text{F between speaker} = \frac{\text{MS between speaker}}{\text{MS residual}} = \frac{51.7}{27.9} = 1.85 \text{ N.S.}$$

$$\text{F within speaker} = \frac{\text{MS within speaker}}{\text{MS residual}} = \frac{28.6}{27.9} = 1.03 \text{ N.S.}$$

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